SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

NEW

HOW IT WORKS

The Collection

1000s OF AMAZING FACTS INSIDE

Digital Edition

FUTURE

THIRD EDITION

Feed your mind and learn more about the incredible world around you

Welcome to

HOW IT WORKS

The Collection

Volume 3

How It Works The Collection is a compendium of the planet's most incredible facts that will feed your mind and give you answers to questions you've never even thought to ask!

Through in-depth articles, detailed illustrations and eye-catching images, we delve deep to answer some of the biggest what-ifs, uncover the truth behind Thor's Well, and look at what we can do about the plastic crisis.

Over the following pages, examine science, technology, the environment, transport, space and history. Topics range from engineering marvels, including the future of buildings, to the megalodon shark, a prehistoric predator. Travel to space, and uncover how the Trans-Siberian Railway was built before taking a trip to the North Pole. Read on to learn more about the world around you!

FUTURE

HOW IT WORKS
The Collection
Volume 3

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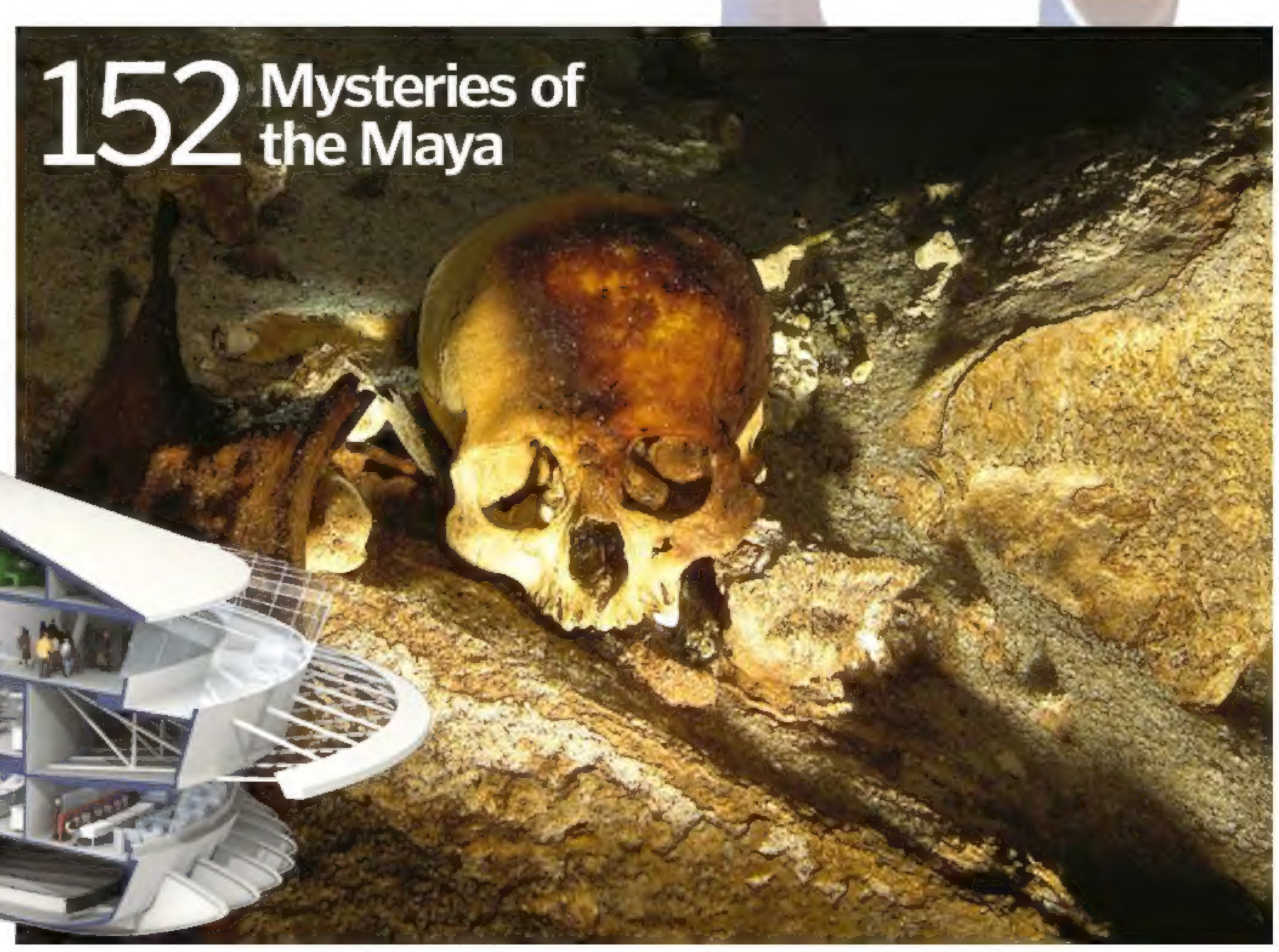

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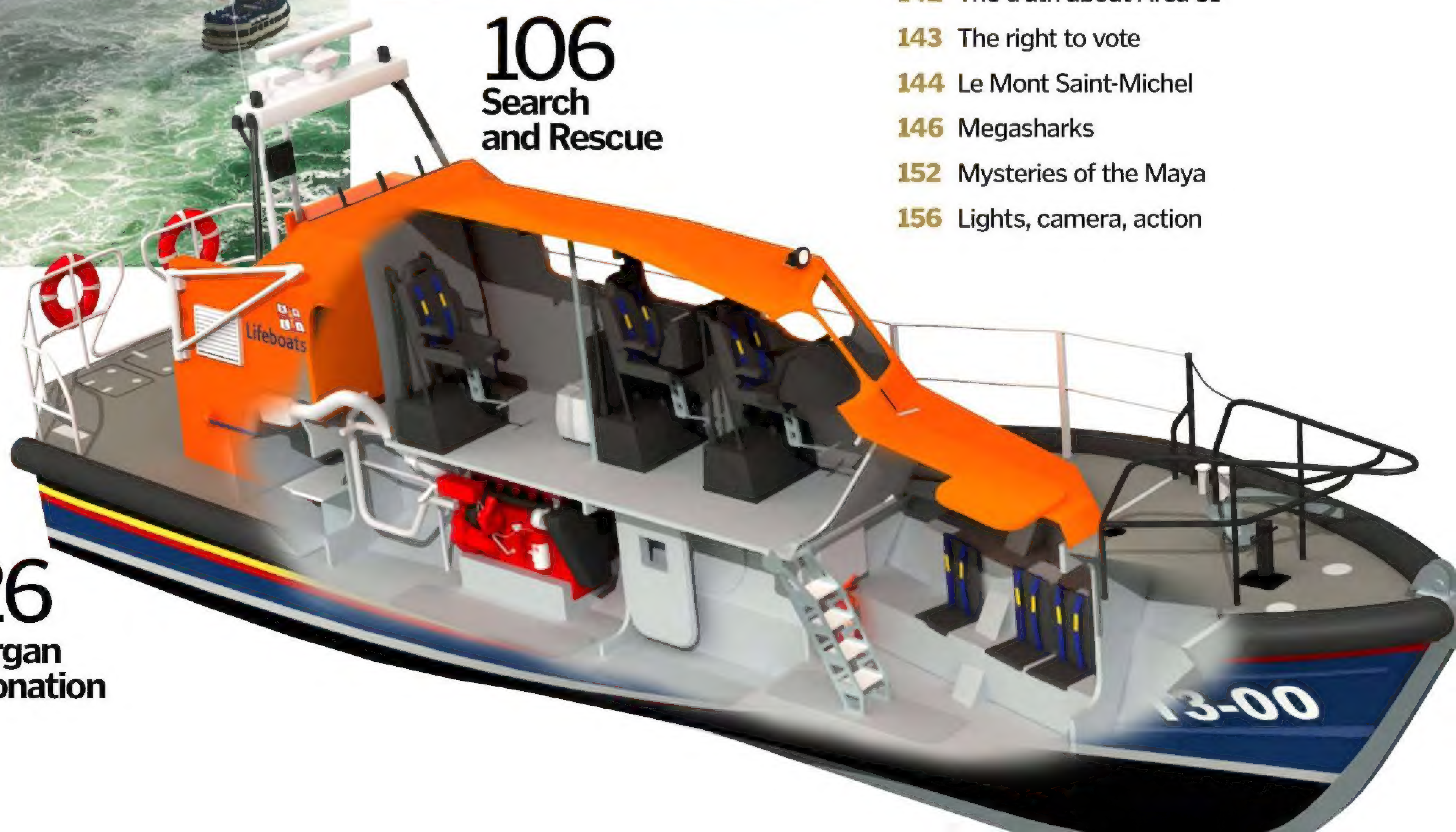

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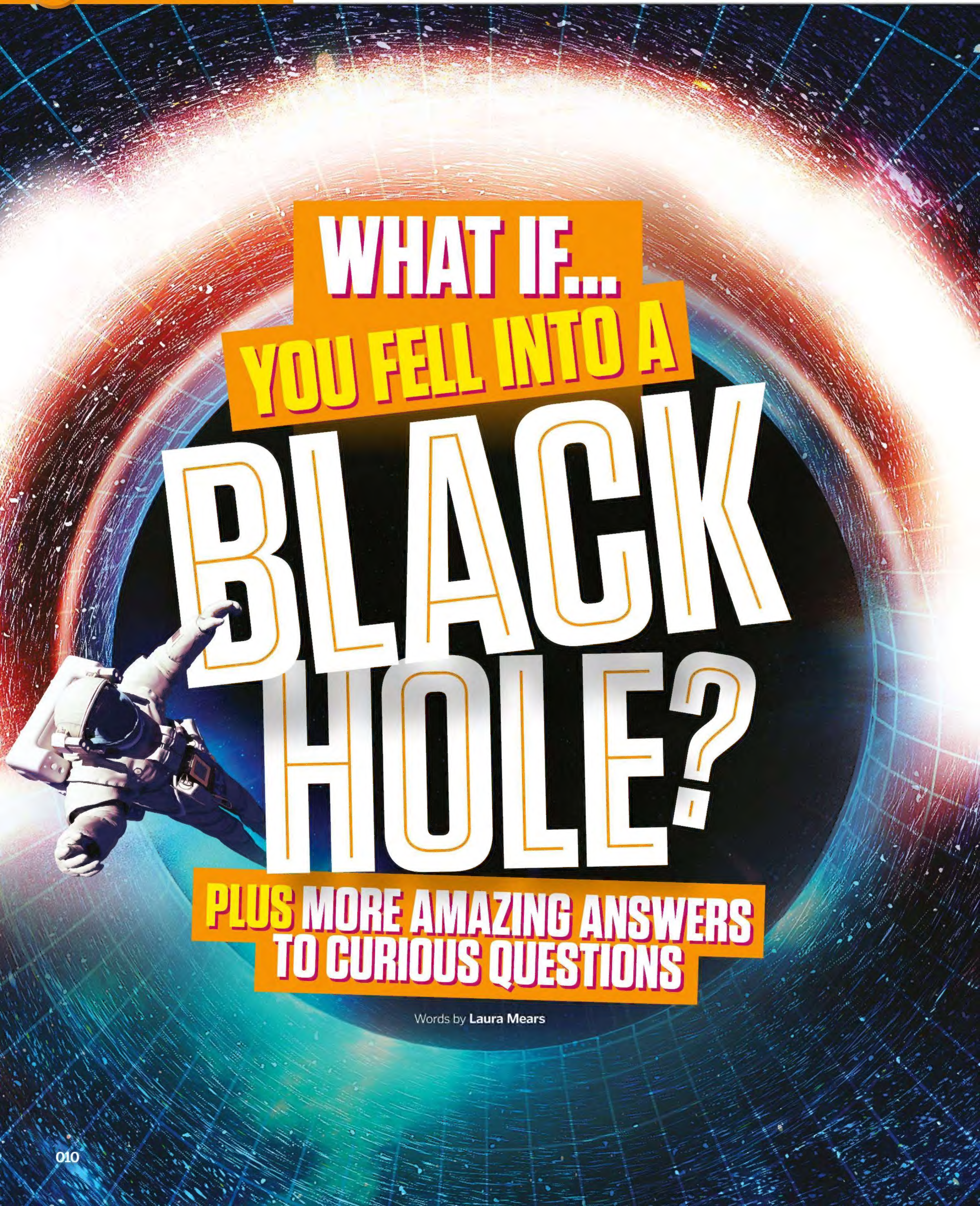
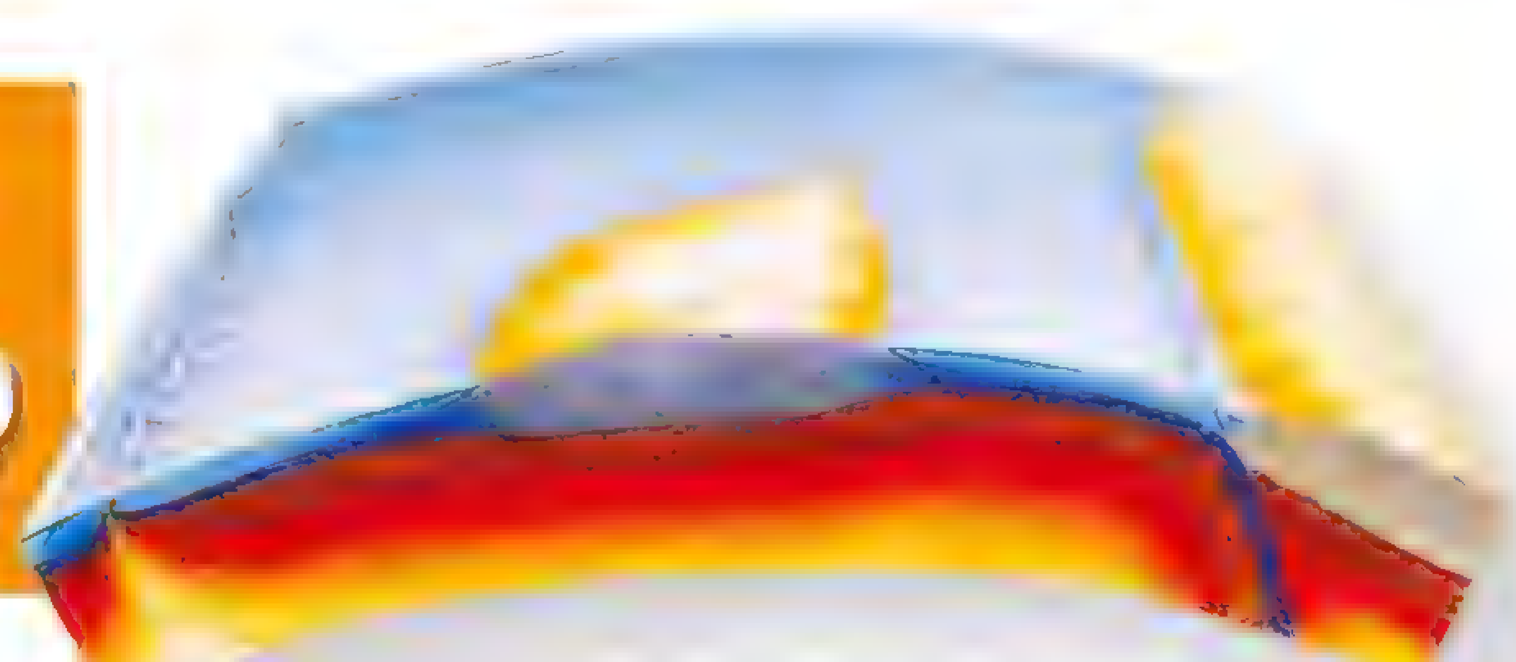


WHAT IF... YOU FELL INTO A BLACK HOLE?

PLUS MORE AMAZING ANSWERS TO CURIOUS QUESTIONS

Words by **Laura Mears**

Q WHAT IF ANOTHER SUPERCONTINENT FORMED?


A new mountain range appears on the left while one plate sinks under another on the right

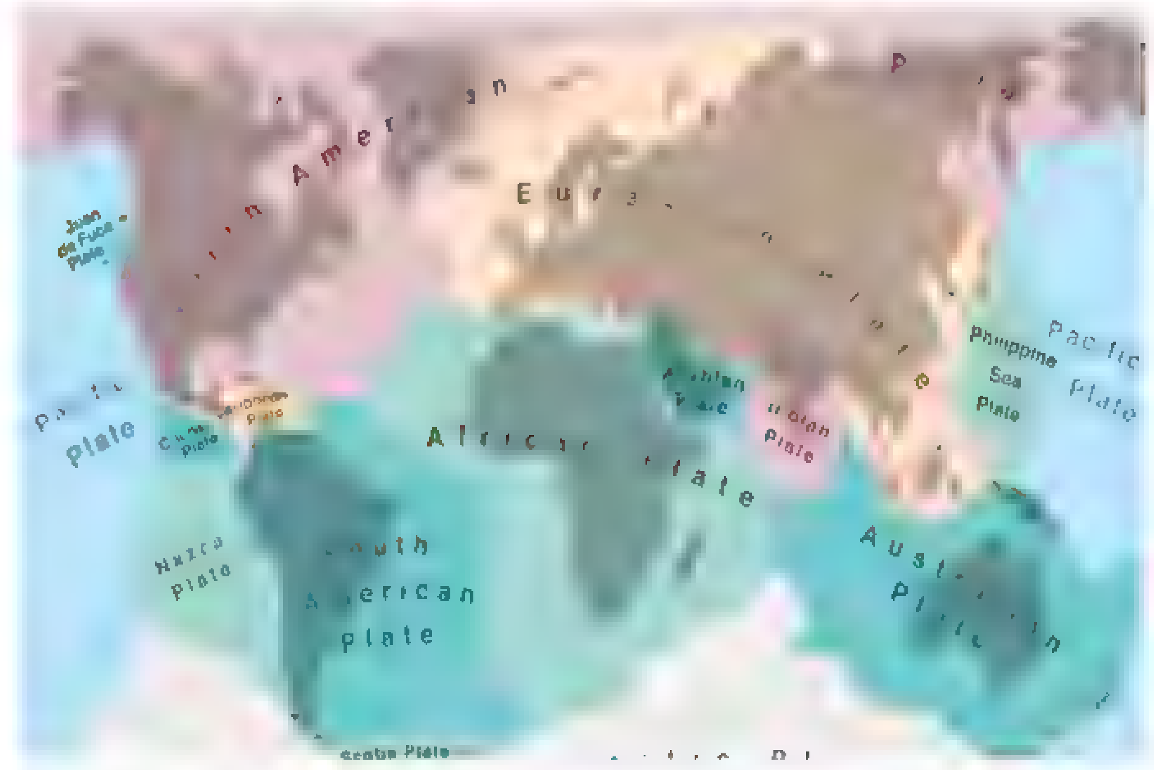
The tectonic plates that carry Earth's land masses are still moving beneath our feet

Earth's crust isn't solid; it's made of seven major and ten minor tectonic plates, which shift and slide over molten rock, crunching together or spreading apart. They move at around the same speed your fingernails grow, and throughout Earth's history they've taken many different forms. At several points, all Earth's landmasses have come together to form supercontinents, and traces in rock suggest that it might happen again.

Scientists aren't in total agreement about how the next supercontinent will look; it all depends on what happens to the tectonic plates that sit under the oceans. When oceanic plates collide with other plates, subduction zones can emerge (one plate dips under the other and melts into the mantle). This is happening in the Atlantic, the Pacific and in the Arctic Circle, causing plates to shrink and shift.

Work by geophysicists at Yale University suggests that the Arctic Circle might be the location for the next supercontinent. When rock is molten, iron atoms pull into line with Earth's magnetic field. Then, as the rock hardens, their position fixes. This leaves a trace of the direction in which landmasses were facing when they formed, so as continents shift around we can see where they came from. By looking at these traces, the team of scientists found that the centre of each supercontinent was around 90 degrees away from the centre of the last one. If the next one follows this pattern, it will surround what is now the Arctic Circle.

"Tectonic plates move at around the same speed your fingernails grow"


Earth's surface is a mosaic of sliding tectonic plates

The breakup of Pangaea

How did we get to the seven continents that we see on Earth today?

The last supercontinent

200 million years ago Earth's land was all part of the continent Pangaea and the sea was all one ocean, known as Panthalassa, Greek for 'all sea'.

Laurasia and Gondwanaland

Pangaea split in two 180 million years ago. Laurasia contained North America, Europe and Asia. Gondwanaland contained Antarctica, Australia and South America.

Today's continents emerge

Laurasia and Gondwanaland broke apart into the modern continents 130 million years ago.

Change continues

The Atlantic Ocean widens and the Pacific Ocean shrinks, forcing the continents apart.

5 FACTS ABOUT PREHISTORIC SUPERCONTINENTS

1 Pangaea
The last supercontinent existed only 280 million years ago. Reptiles had just emerged, a mass extinction was imminent, and dinosaurs were about to appear.

2 Rodinia
This supercontinent covered Earth around 1 billion years ago, supporting the first multi-celled life on our planet. Plants emerged first, and animals soon followed.

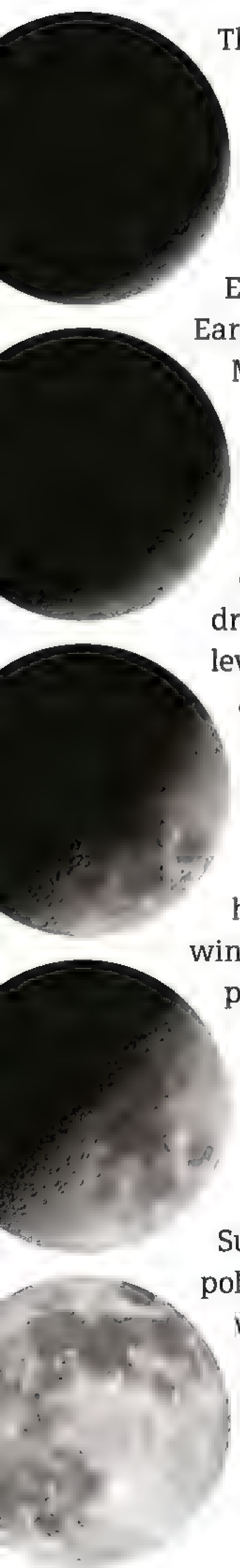
3 Nuna
Also known as Columbia, this supercontinent dates back around 1.8 billion years. At this point in Earth's history, complex cells were just starting to emerge.

4 Kenorland
This supercontinent appeared around 2.4 billion years ago, around the time that oxygen levels started to rise in the atmosphere. Air became breathable, but it triggered an ice age.

5 Vaalbara
This supercontinent existed 3.1 billion years ago, just after photosynthesis started to fill the atmosphere with oxygen. Only two pieces remain, one in South Africa and one in Australia.

Q WHAT IF EARTH DIDN'T HAVE THE MOON?

Our planet's lifeless companion has helped to make our world habitable



The Moon appeared around 4.5 billion years ago when a chunk of rock the size of Mars smashed into our planet. It's only around one-quarter of the size of Earth, but everything on Earth would change if the Moon disappeared.

The gravitational pull of the Moon tugs on Earth's oceans, pulling them out into a bulge at the equator. Not only does this drive the tides and affect sea levels across the planet, it also slows down our rate of rotation. If the Moon disappeared, we'd speed up until we were spinning around every six hours, whipping up lethal winds of over 160 kilometres per hour!

The Moon also keeps us stable; without it, Earth's axis would tip every few million years. First, the equator would point at the Sun, then we'd slip and the poles would face our star. This would make the climate so unstable that life would struggle to adapt.

Ancient farmers used the light of the full Moon to work the fields at night

No-oxygen Earth

A few seconds without oxygen could spell the end of life as we know it

Q WHAT IF OXYGEN DISAPPEARED FOR FIVE SECONDS?

"Around 21 per cent of Earth's atmosphere is oxygen"

We wouldn't suffocate but the world would be in chaos

If you've ever tried holding your breath, you'll know we can go a lot longer than five seconds without oxygen. But if oxygen disappeared the world would turn to chaos.

Around 21 per cent of Earth's atmosphere is oxygen, and without it atmospheric pressure would drop. Our ears would pop and we'd get decompression sickness as the other gases inside our bodies expanded. Every fire would go out, combustion engines would stall, and cars, planes and trains would coast or crash. Plastic polymers would fall to pieces, rocks would crumble, and oxides would disappear, cold welding all metal surfaces together in an instant.

Q WHAT IF THE SUN WERE HALF AS BIG?

A smaller star might last longer, but Earth would be a very different planet

Earth sits in an orbit around the Sun called the habitable zone. This 'Goldilocks' region of stellar space is not too hot and not too cold, just right for liquid water to flow freely in Earth's lakes, rivers and oceans. The position of this zone depends on the size of our star, and if the Sun suddenly halved in mass, everything would change.

The Sun is a G-dwarf star, also known as a yellow dwarf. It fuses hydrogen atoms together to make helium, generating a surface temperature of between 5,300 and 6,000 Kelvin (around 5,000 to 5,700 degrees Celsius). A star half its size would be an M-dwarf star, also known as a red dwarf, with a much lower temperature of between 2,500 and 4,000 Kelvin (2,200 to 3,700 degrees Celsius). To keep our water liquid around this kind of star we'd need to orbit much closer, and that would cause some problems.

Huddling close to a red dwarf star would generate strong tidal forces. This would slow Earth's spin, lengthening our days. It's possible that we'd decelerate so much that we'd become locked in one orientation, with one side of the planet always in daylight and the other in perpetual darkness. If this happened, our water might freeze or boil away, leaving Earth barren and lifeless.

Our star in numbers

142mn km The inner edge of the Sun's habitable zone

150mn km Earth's distance from the Sun

4,500,000,000 years The Sun's age

5,000,000,000 The estimated number of years the Sun has left

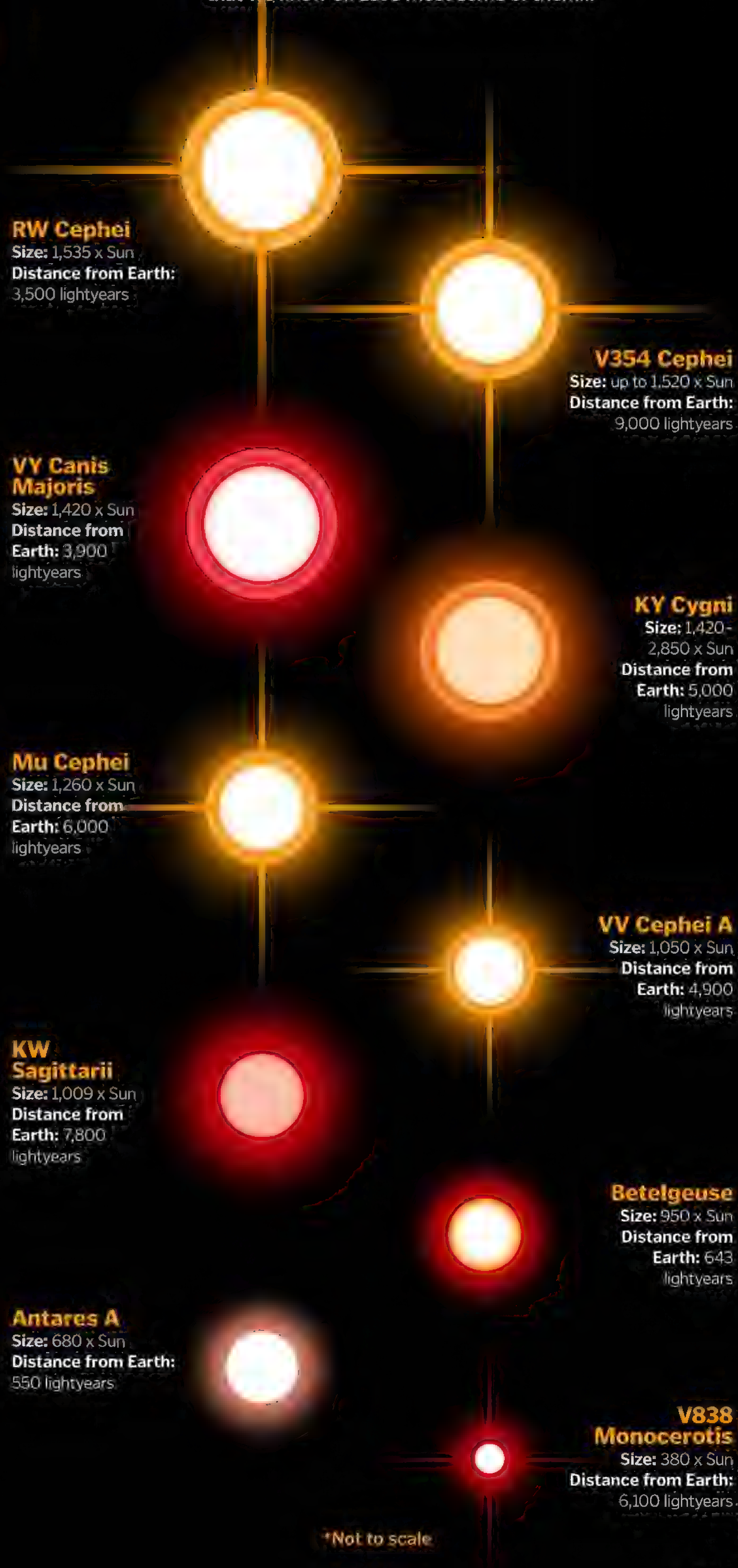
8 mins How long it takes light to reach Earth from the Sun

450 KPS The speed of solar wind

960,000 The number of Earths that would fit inside the Sun

Supersize stars

Our Sun is puny compared to many other stars that we know of. Let's meet some of them...

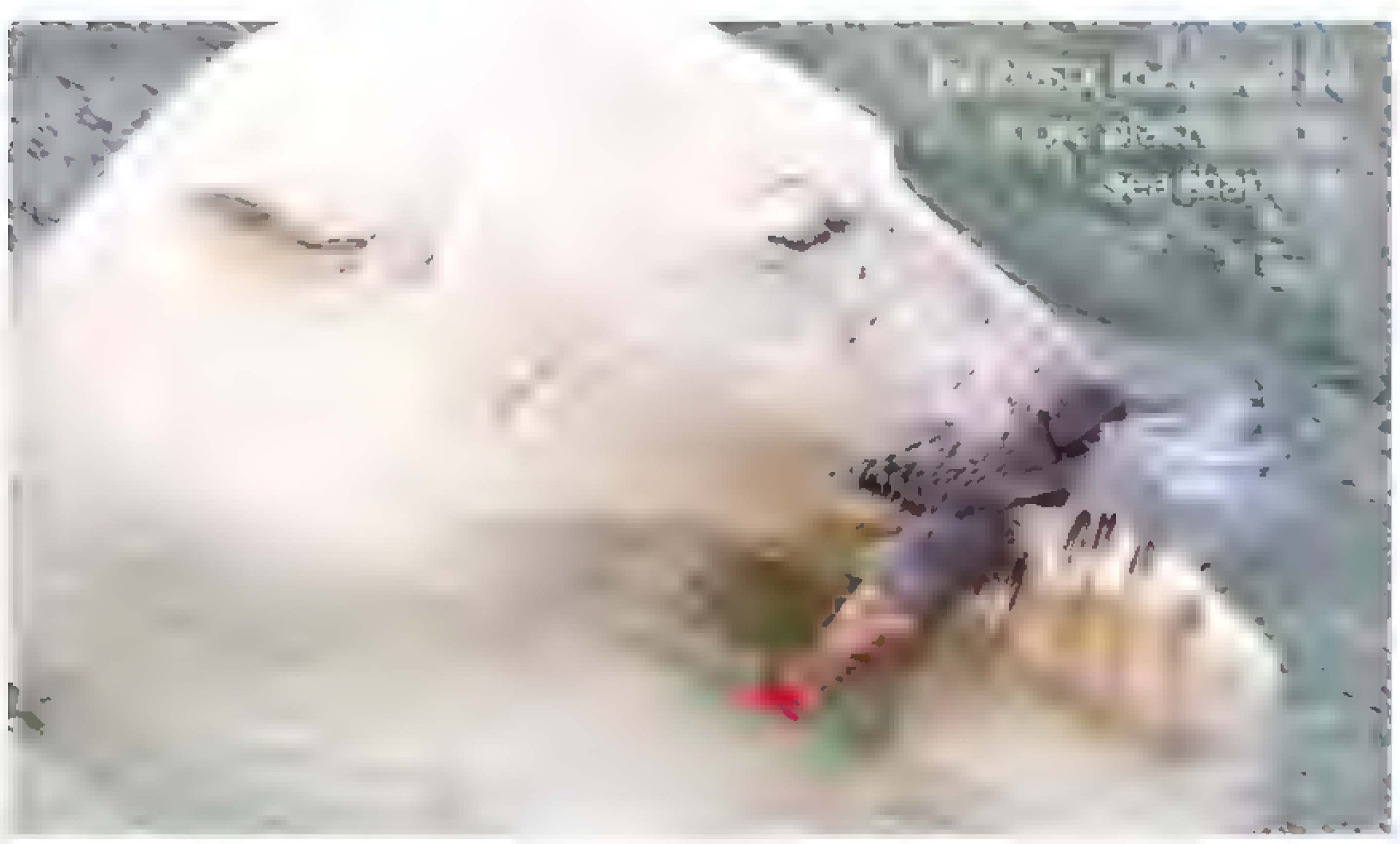


Q WHAT IF PLASTIC WAS NEVER INVENTED?

The modern world just wouldn't work without this wonder material

There is plastic in your teabags, it makes your socks stretchy, and it stops the fat in your packet of crisps going rancid. It's used in life-saving medical technology, like syringes, catheters and incubators. It forms the circuit boards inside your phone, the insulation that wraps the wires in your house, and it makes planes light enough to fly. Without it, the modern world as we know it would not exist.

Plastic is one of the most versatile materials ever invented, but it's become so cheap we don't think twice about throwing it away. According to research from the University of California, we have made over 8 billion tons of plastic, and we have thrown three-quarters of it away. We have sent 79 per cent to landfill, burnt 12 per cent and recycled nine per cent, all since the 1950s. Unlike with organic waste, most bacteria simply won't touch plastic, so it doesn't matter how long we leave it, it will never biodegrade.



We make **150 million tons** of single-use plastic a year.

We use plastic bags for an average of just **15 minutes** before throwing them away.

We buy **1 million** disposable plastic bottles **a minute**.

It takes **450 years** for a plastic bottle to break down.

Each year **8 million tons** of plastic ends up in our oceans.

Your body would stretch like a piece of spaghetti as you fell into a black hole

Q WHAT IF YOU FELL INTO A BLACK HOLE?

Travelling into the singularity of one of these objects would be the one-way trip of a lifetime

A black hole has one of the strongest gravitational pulls of any object in the universe; get caught in its clutches and you're doomed. Beyond a point called the event horizon, space and time curve so extremely that even light cannot escape. Inside, matter crushes down to a single point, called a singularity. This black spot is completely invisible because light can't get out. Even so, you can see the effects from the outside.

If you got close to a black hole you would see light starting to bend, swirling around the central dark point like water going into a plughole. You'd start to move faster and faster as gravity tugged you in and, if you were travelling feet first, you'd see strange things happening to your body. Your feet, closer to the black hole than your head, would experience a stronger pull and your body would start to stretch. If the black hole were small, you'd rip apart, but if it were large, you'd carry on spinning.

When you crossed the event horizon everything would go dark, but you wouldn't have long to look around. You'd become part of the black hole, crushed to a speck with no chance of escape.

5 FACTS ABOUT BLACK HOLES

1 They really are supermassive
Stellar black holes are only around ten or 20 times more massive than the Sun. Supermassive black holes are millions of times more massive.

2 Galaxies spin around them
There may be a supermassive black hole in the middle of every large galaxy in the universe. All the stars orbit around the outside.

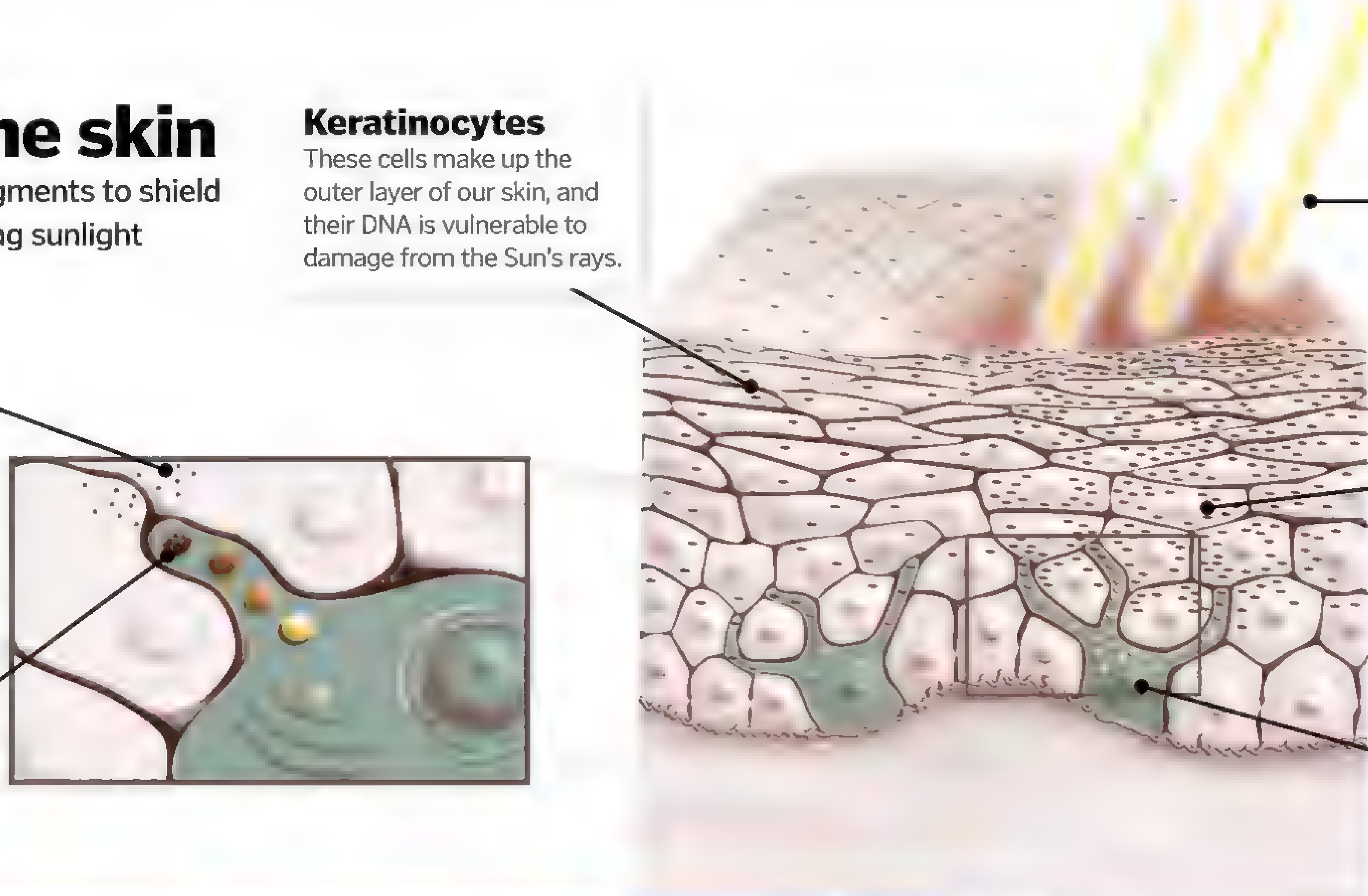
3 They burp
The NASA's Chandra X-ray Observatory revealed that black holes belch out streams of high-energy particles as they feast on gas from nearby stars.

4 Only one photograph exists
Astrophysicists have only ever managed to get one photograph of a black hole, which was released in 2019, thanks to the Event Horizon telescope network.

5 We orbit one
Sagittarius A* is a supermassive black hole at the centre of the Milky Way. Don't panic, it's 26,000 lightyears away.

Shielding the skin

Melanocytes make dark pigments to shield the skin cells from damaging sunlight



Q WHAT IF WE COULD FILTER OUT ALL ULTRAVIOLET LIGHT?

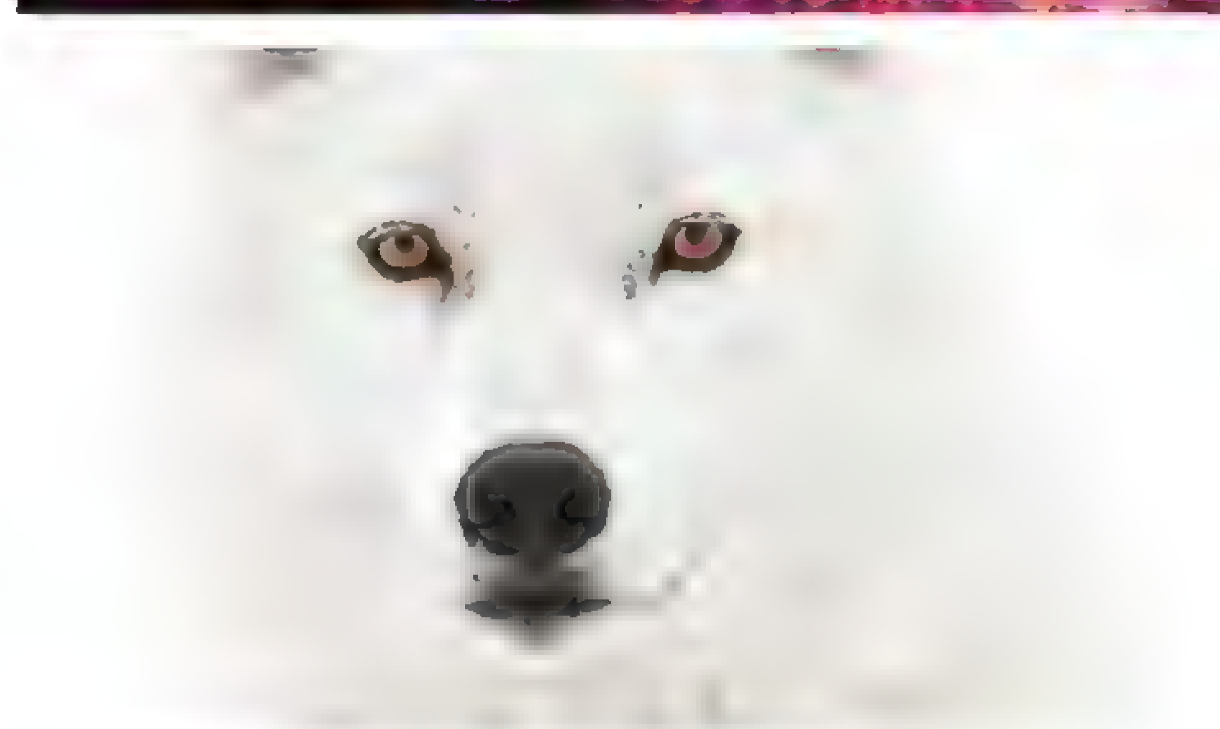
Blocking UV would do away with skin cancer and premature ageing, but at what cost?

Scientists split UV into three bands of wavelengths based on their behaviour. At the most energetic end – 100 to 290 nanometres – there's UVC light; it has the shortest wavelengths and does the most harm. Luckily, the atmosphere filters it all out before it gets to the ground. Between 290 and 320 nanometres there's UVB light; this is the one that tans and burns the skin and causes cancer. The atmosphere gets rid of around 95 per cent of it, and it can't travel far into our bodies, but the little that gets through is enough to do us harm.

Finally, from 320 to 400 nanometres there's UVA; it passes through the atmosphere and through the skin causing damage to the structures that support our cells. This leads to premature ageing, cataracts and sunburn. Blocking this light could save us from having to apply sunscreen, but it wouldn't all be positive.

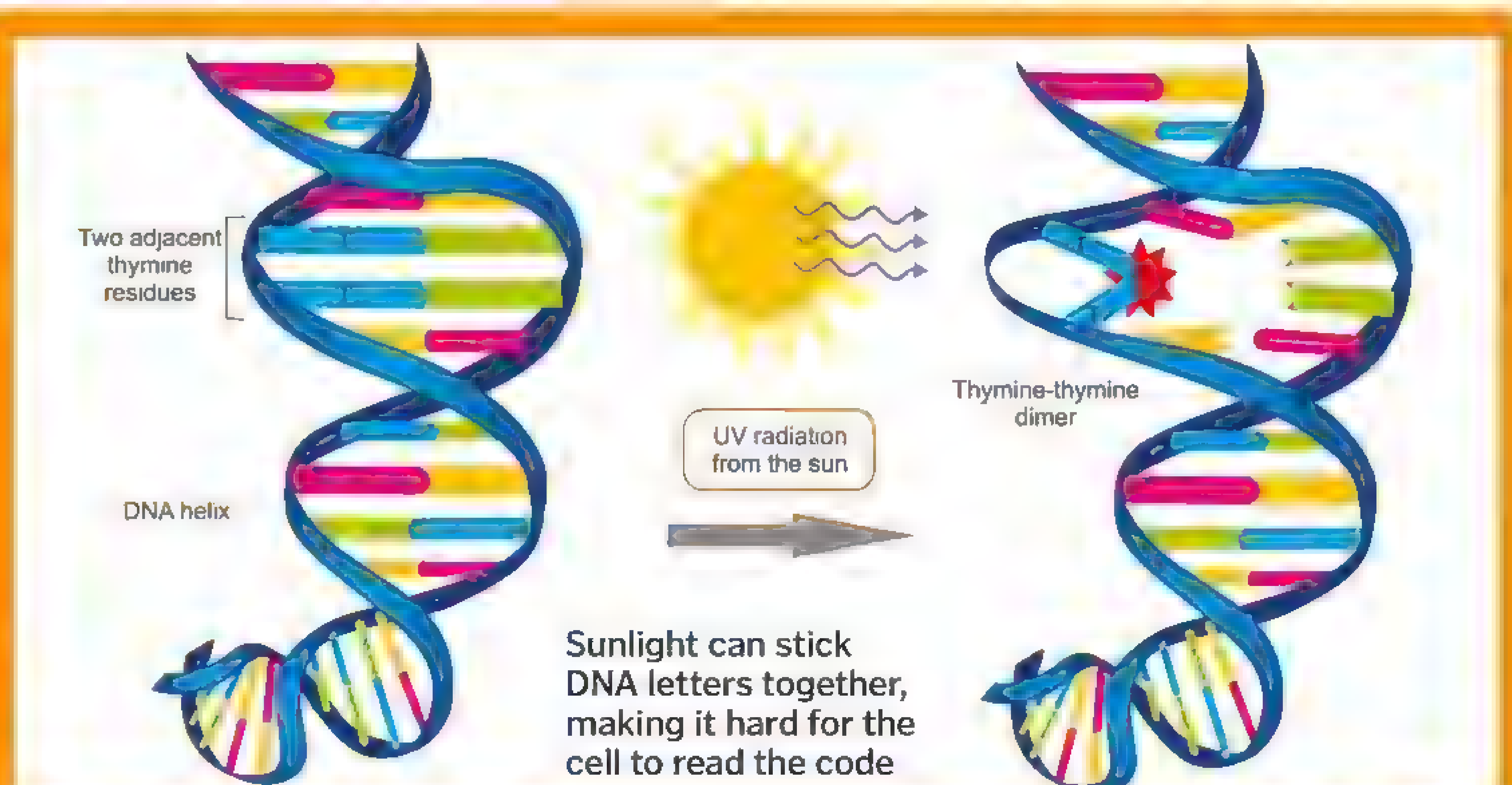
Our bodies use UVA light to make vitamin D, and lots of animals also rely on UV for survival. Butterflies use UV in their wing patterns to attract a mate, flowers use it in their petals to attract bees, and sockeye salmon use it to find food. In the Arctic, UV light allows reindeer to spot wolves, whose fur and urine show up black against the snow. And that's just the tip of the iceberg; research is revealing that dozens of other species can see into the UV spectrum. If we got rid of UV light, they'd all be left in the dark.


Flowers display intricate patterns to bees, visible only under UV light


Ultraviolet vision can make it easier for animals to spot predators in the snow

What does UV light do to DNA?

When photons of light hit DNA, they heat it up and make it more likely to react with molecules around it. Most of the time the heat is simply released and the DNA goes back to normal, but sometimes two adjacent DNA letters get stuck together. There are four DNA letters – adenine, cytosine, guanine and thymine – and it is cytosine and thymine that are most vulnerable. Their ring-shaped structures can get stuck together, and this makes it hard for the cell's machinery to read the genetic code. When it gets to a pair of stuck rings, it can't work out the sequence, so it has to guess. This can introduce mistakes into the code as the cell copies its genes, and these mistakes can change the way that proteins work. This can then change the way that cells work, leading to skin cancer.



Sunlight can stick DNA letters together, making it hard for the cell to read the code

Q WHAT IF ALL THE VOLCANOES ON EARTH ERUPTED AT ONCE?

The simultaneous eruption of more than 1,500 active volcanoes would be absolutely catastrophic

Of the thousands of volcanoes currently active on our planet, there are a handful that could seriously harm life on Earth if they blew. If they all erupted at once, we'd be done for. Cone-shaped stratovolcanoes would spew sticky magma upwards in violent bursts, splattering the ground with molten rock. Dome-shaped shield volcanoes would dribble runny lava out across the floor, engulfing anything in its path. Fissure vents would make curtains of fire and vast lava lakes would open as the ground collapsed. But these would be the least of our problems.

Within moments, ash would bury the Earth. Our machines would stop working, buildings would collapse, animals would suffocate, and crops would fail. Sulphurous gases would rise high into the atmosphere, blocking out the Sun's light and plunging the whole planet into winter. Then, as the gases mixed with water, they'd rain down on the ground as acid. Oceans would become acidic, the shells of sea creatures would dissolve, and food chains would collapse. In the aftermath, carbon dioxide would create a greenhouse effect, heating Earth so fast that life would struggle to adapt. Only time would tell which organisms, if any, would be able to survive.

Flowing lava consumes everything in its path, from trees and animals to roads and houses

Did volcanoes kill the dinosaurs?

A colossal asteroid struck the Earth just before the dinosaurs died, but it wasn't the only natural disaster to befall our reptilian predecessors. In a part of India called the Deccan Traps, 512,000 cubic kilometres of solidified lava coat the ground, the result of monumental volcanic activity. Eruptions on this scale would have released tons of carbon dioxide into the atmosphere, dramatically changing the climate.

The rock at the Traps dates back to between 60 and 65 million years ago – just before the dinosaurs disappeared. Studies of a lakebed in China have revealed evidence of rising temperatures and accelerating extinctions around the same time. It looks like the dinosaurs were already under pressure from volcanic eruptions; the asteroid might just have been the final nail in the coffin.

The Deccan Traps in India contain solidified lava flows over 2,000 metres thick

Volcanic Earth

Thousands of simultaneous eruptions would turn Earth into a ball of ash, glass and fire

Q WOULD ANYTHING BAD HAPPEN IF WE MADE WASPS EXTINCT?

A delicate balance depends on these picnic pests

Wasps might seem like good-for-nothing pests, but they aren't all bad. In the UK alone there are more than 7,000 different species, although we're most familiar with the 'yellow jackets', *Vespula vulgaris*.

These social wasps live in colonies with a queen and hundreds of female workers. The reason they come out in late summer to attack our outdoor meals has to do with the way they raise their young. Wasp larvae make a sweet juice for adult wasps to eat, but by August the young are all fully grown. So the adults, still craving a sugar fix, head out in search of fizzy drinks, jam and cake.

Getting rid of them isn't the answer; wasps play a critical role in controlling insect numbers. They catch and kill pest like greenfly and caterpillars, keeping ecosystems in balance and protecting our gardens from destruction. If they went extinct, our picnics would just be overrun with other insects.

Jam-hungry yellow jackets invade your barbecue in search of a sugar fix

Q WHAT IF ALL OUR ANTIBIOTICS STOPPED WORKING?

Antimicrobial susceptibility tests reveal which antibiotics can kill certain types of bacteria

Bacteria are waging war on our drugs, and defeat is not an option

Until the 1940s, one in 20 children died before their first birthday. Tuberculosis and pneumonia had no cure, and a simple cut could turn a limb gangrenous, resulting in amputation. Antibiotics stop bacteria dividing, slow their growth or burst them open, helping our immune cells to clear infections. They eliminate deadly diseases, allow us to open the body up for surgery and protect cancer patients from infection. They make it possible to farm animals and fish on an industrial scale, and their presence in cleaning products stops the spread of disease. But bacteria are fighting back. In 2016, 700,000 people died as a result of antibiotic-resistant infections, and by 2050, 10 million lives a year could be at risk.

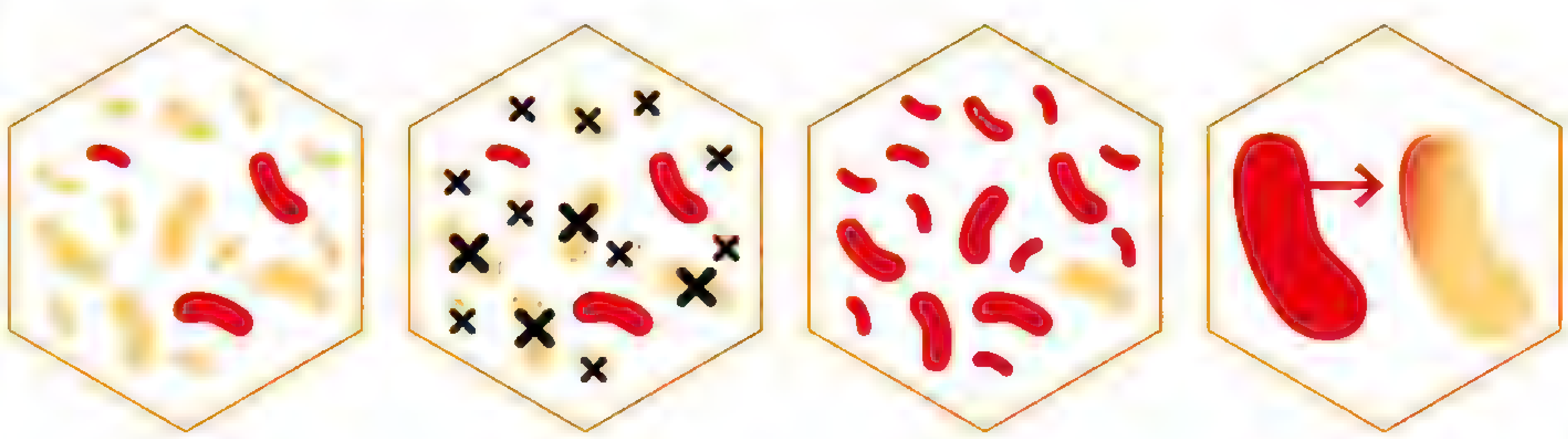
Like us, every individual bacterium is slightly different, so when a colony of bacteria encounter antibiotics, Darwin's survival of the fittest kicks in. Some individuals do better than others, living longer and passing on their genes. This makes the next generation a little bit better at resisting the effects of drugs. That next generation also accumulates random mutations, making them each a bit different from one another again. Some get even better at resisting antibiotics and the cycle repeats. These small improvements start to add up, and eventually we end up with bacteria that we just can't kill.

We are in an arms race with these microscopic organisms. They are evolving molecules that ignore antibiotics, inactivate them, or even pump them out of their cells. What's more, thanks to a quirk of bacterial biology, once one species has developed a way to resist a drug, it can donate its genetic code to another species, passing the resistance on. If our drugs stop working, treatable infections could once again become deadly, the risk of infection after surgery could rise, and industrial farming could become impossible. It's a race against time to find new ways to fend them off, a race that we can ill afford to lose.

The more we use antibiotics, the more chances bacteria have to develop resistance

The rise of resistance

As bacteria fights back, the antibiotic war is far from over



A mixed army
Each bacterium in a colony is slightly different – some are naturally a little harder to kill than others.

The strong remain
Antibiotics kill or inactivate the weakest bacteria first, thereby leaving the stronger bacteria behind.

Share to survive
The offspring of the surviving bacteria inherit the genes that make them harder to kill.

Resistance
Bacteria can share genes, allowing them to pass antibiotic resistance to other species.

FOOD WASTE

Follow the food that goes uneaten on the journey from field to fork

How many times have you bought some fresh fruit just for it to end up in the bin just days later, or emptied your leftovers into the bin? It happens to the best of us – impulse buying, improper planning and being forgetful means a large amount of the food we buy goes uneaten. But the biggest cause for concern when we're thinking about food waste is what happens between the produce growing on the field and arriving at your kitchen. It is estimated that between one-third and one-half of all food produced never makes its way onto a plate.

THE JOURNEY OF AGRICULTURAL FOOD WASTE

Losses occur at all stages of the food supply chain, from production to consumption

INITIAL QUANTITY
According to a UN report from 2011, approximately 4 billion tons of food is produced globally each year, but one-third of this ends up going to waste.

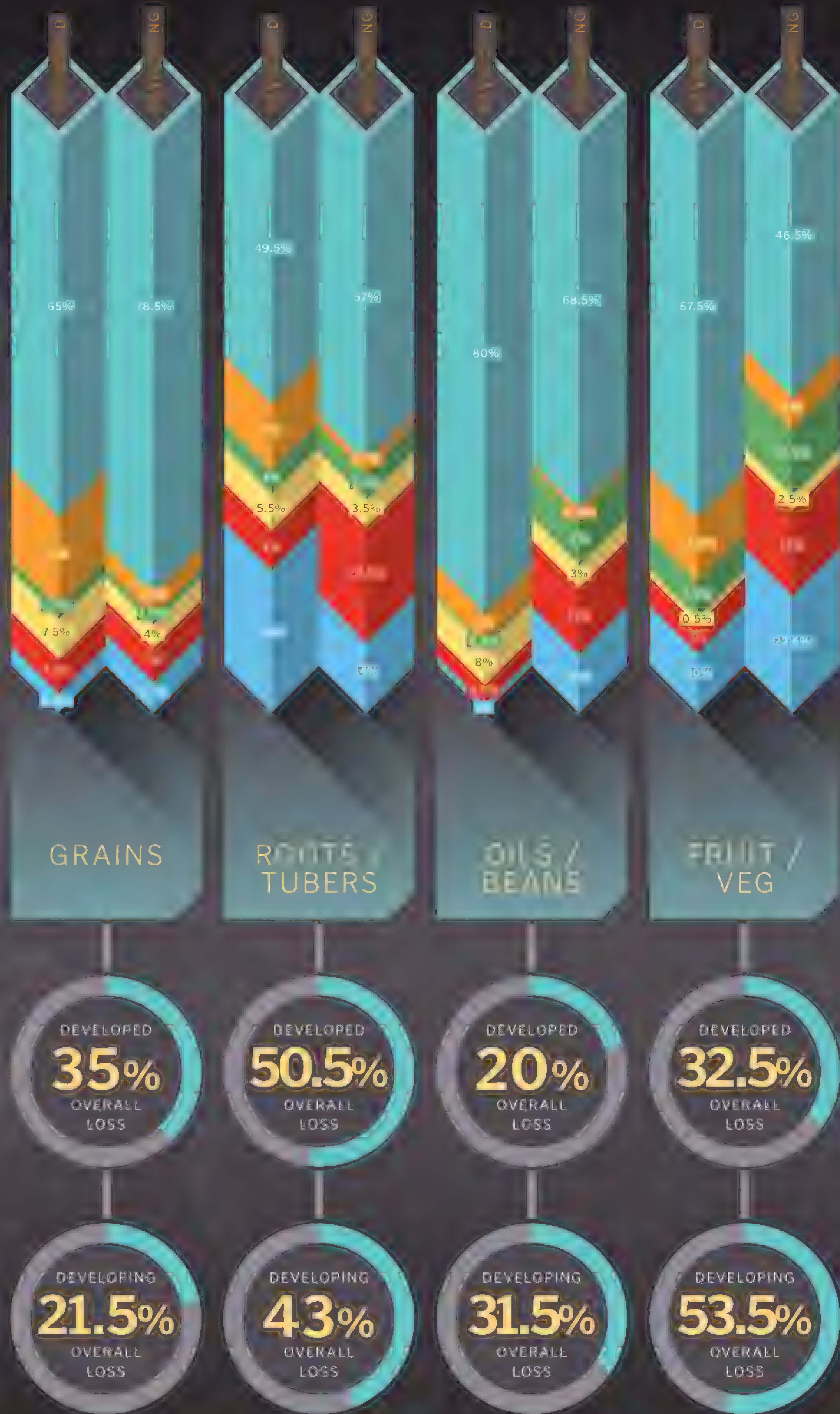
AGRICULTURE
The first losses in food production occur due to infestations of pests and microorganisms, as well as agricultural machines that are unable to harvest an entire crop efficiently. Diseased livestock and fish bycatch also lead to losses.

POST-HARVEST
After harvest, many items of produce can end up getting damaged or destroyed while in storage or being transported due to temperature and humidity changes or the presence of microorganisms and pests.

PROCESSING
Edible food can end up going to waste in factories and processing plants. This can include the skin of 'ready-peeled' veg or trimmings of meat, as well as products that have been contaminated or don't conform to standards.

DISTRIBUTION
Retailers usually have strict standards for how produce must look; items may not be put on the shelves if they have bruising or are unusually shaped. Stores may also reject food deliveries if they have surplus stock already.

CONSUMPTION
Large portion sizes at home and in restaurants, as well as misunderstanding 'best before' labels, means a significant amount of good food is thrown away at the consumer end of the food production chain.

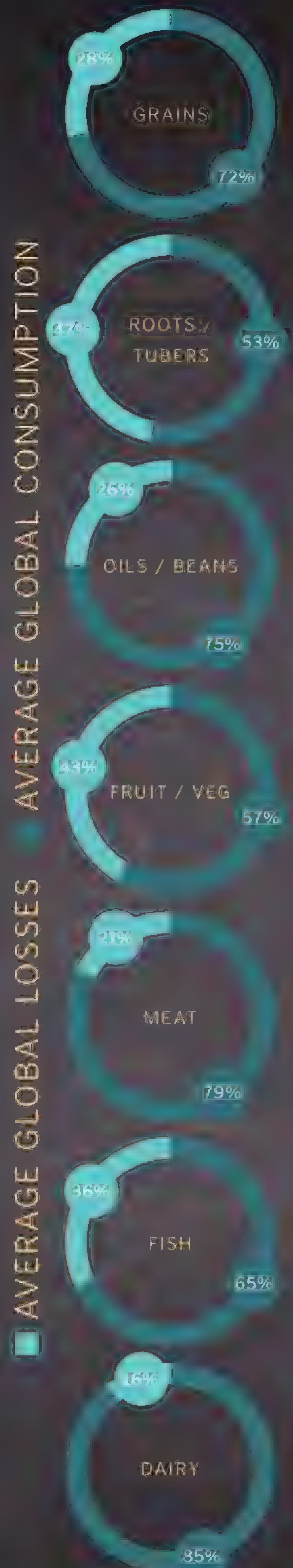


FOOD WASTE SOLUTIONS

Better labelling
There is often confusion around what the 'use-by', 'sell-by' and 'best before' dates on packaging mean, so consumers often throw away food that was good to eat. Using 'spoils on' dates rather than a sell-by date could mean that markets can keep produce on the shelves longer.

Food distribution
Overstocked stores can help to reduce waste by redistributing their surplus stock. They can send any extra food they don't need to food banks, community fridges and similar schemes. There are even apps that can help – Food Cowboy helps connect companies donating spare food with those who need it.

DID YOU KNOW? *Approximately 1.3 billion tons of edible food gets lost or wasted each year – enough to feed 2 billion people*



5 TIPS TO… REDUCE FOOD WASTE AT HOME

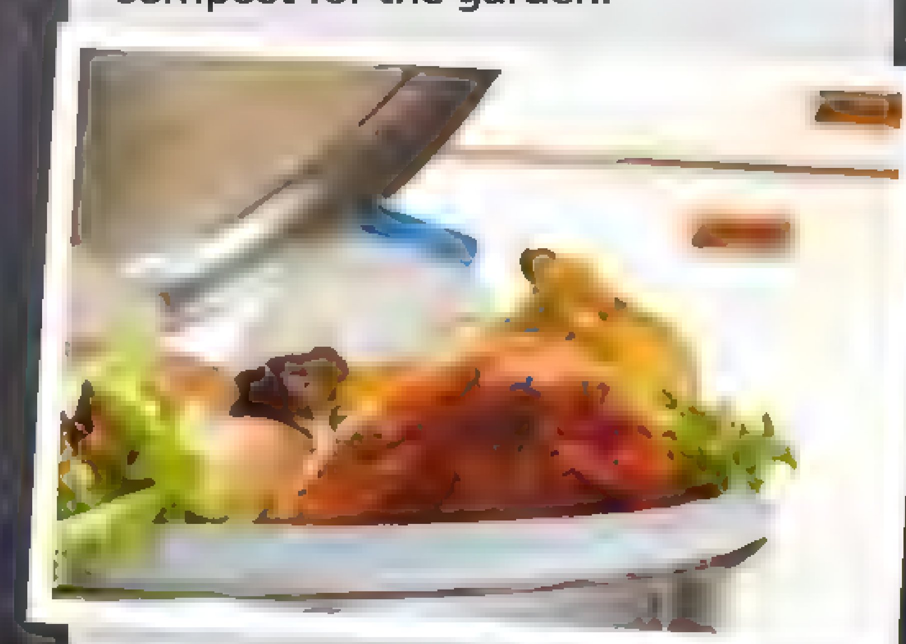
1 Plan ahead
Making a shopping list and planning your meals for the week helps to make sure you only buy the ingredients you will need.

2 Water your vegetables
You can keep vegetables in water to help them stay fresh and keep in your fridge for longer. Try this with stemmed veg such as broccoli, celery and asparagus.

3 Freeze leftovers
Accidentally made too much cottage pie for the family? Invest in some freezer-safe containers and put leftovers in the freezer to save for another time.

4 Get creative
When food has already started to get a bit past its best, check out recipes you can still use it in. Older bananas can be great for making banana bread when they're too mushy to eat on their own, and overripe avocados can still be used in guacamole.

5 Start composting
Rather than throw away vegetable peels or leftovers, you can make your own nutrient-rich compost for the garden.



Consumers can reduce waste by only cooking what they need and planning ahead for meals

© Getty

Improving policy

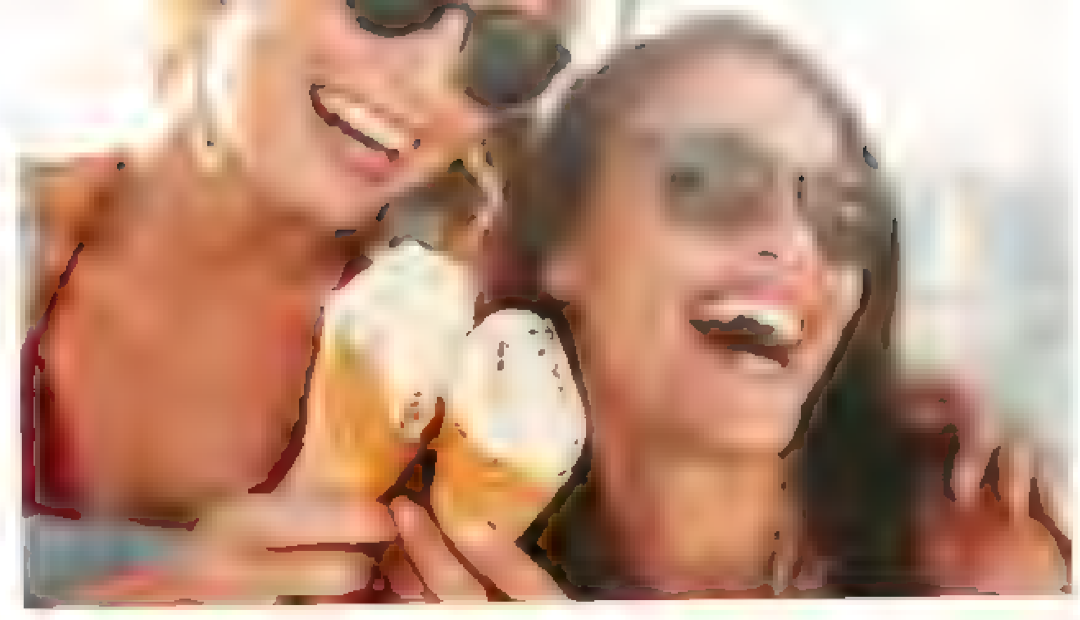
Significant amounts of fruit and vegetables are lost due to industry standards that focus on the appearance of the item rather than its quality. Improving policies surrounding which items are thrown out due to aesthetics would reduce unnecessary waste.

Consumer choices

Consumer choices impact the food supply chain. If we all take steps to reduce waste as individuals – by selecting 'wonky veg' or using up our leftovers instead of throwing them away – it will make a significant difference.

Building infrastructure

Improving current food harvesting methods, storage and transport facilities and processing techniques will make a big difference to the amount of food that is lost at almost every stage of food production.



When ice cream melts its molecular structure breaks down and the air bubbles escape

Ice cream chemistry

From gelato to soft serve, what makes our favourite frozen treats?

Ice cream is made from three main ingredients: milk, cream and sugar. However, you need to do more than just mix and freeze them to create the perfect dessert. Behind this seemingly simple summer treat there is some complicated chemistry at play.

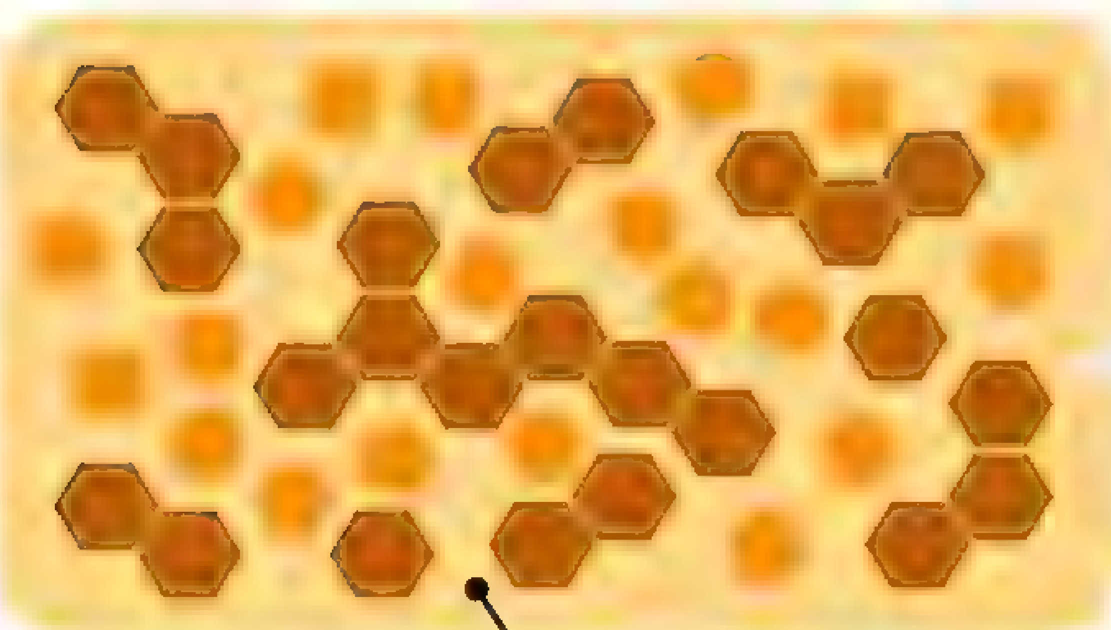
Ice creams are an example of an emulsion; a combination of two liquids that would normally not mix together and are dispersed throughout each other. In ice cream, tiny droplets of fat are dispersed through the water. The fat comes from the cream, mostly in the form of triglycerides. During ice cream production they are aerosolised and broken down into tiny droplets. Milk proteins, which are also added during the production process, coat the fat droplets and prevent them from interacting with one another. This stops them becoming large droplets again, because the proteins stuck to the surface of the fat droplet repel one another.

Many ice creams also contain emulsifiers, which surround the fat droplets and replace some of the milk proteins. This means that the droplets will mix more evenly when they are whipped. As the ice cream is frozen – usually with the help of liquid ammonia – it is also aerated, and the air becomes trapped in the dessert by the arrangement of the fat, protein and emulsifying ingredients.

The final and arguably most important ingredient is sugar. Not only does this make your ice cream taste great, it also lowers the freezing point of the water so you don't end up with chunks of ice in your scoop. Add in some colourings and flavourings and your ice cream is ready to be enjoyed.

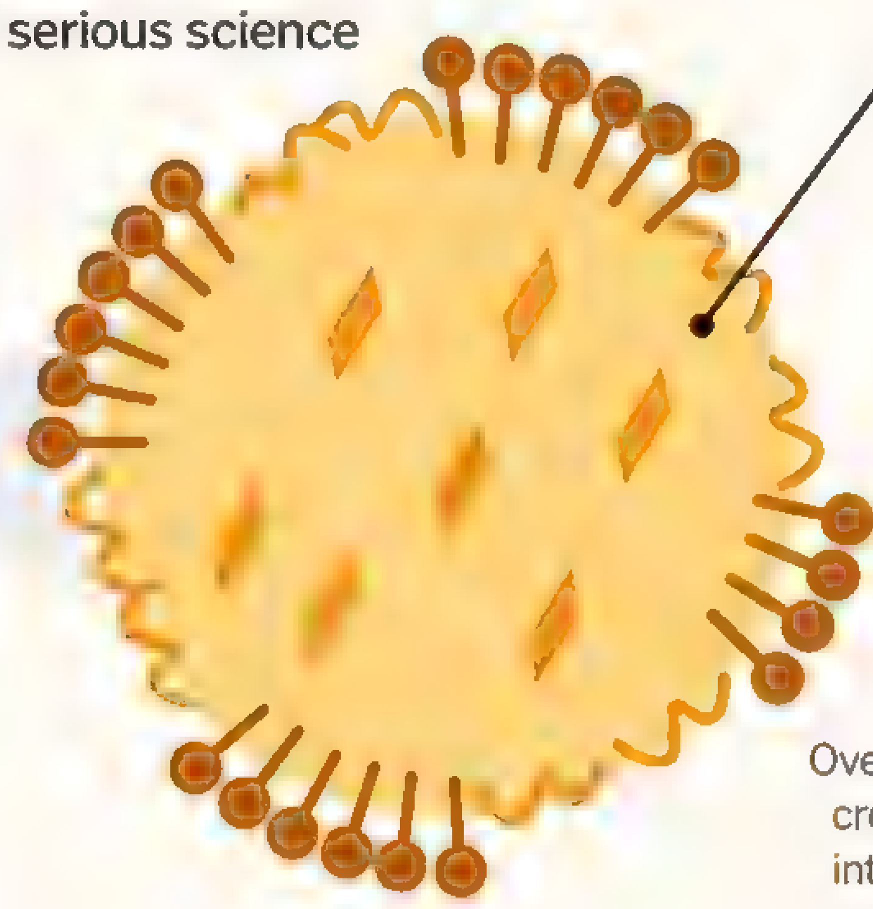
Frozen treats explained

Behind every bite of delicious ice cream there is some serious science



Composition

The chemical composition of ice cream means that the tiny fat droplets are suspended in the water to create a smooth texture and evenly distributed ingredients.



Fat droplet

Each droplet is surrounded by milk proteins and emulsifiers, which improve the mixing of the water and fat.

A SINGLE FAT DROPLET

- Liquid fat
- Emulsifier molecules
- Milk proteins
- Frozen fat crystals

Air bubbles	50%
Ice crystals	30%
Liquid syrup	15%
Fat droplets	5%

% by volume for typical composition of ice cream

Air and overrun

Overrun is the percentage by which ice cream has expanded from having air introduced into it during the freezing process. A standard ice cream will be made at 50 per cent overrun; one part air to every two parts cream.

Texture

The lower the percentage of overrun the thicker and denser the final product, while the higher the percentage the lighter and fluffier the final product. More expensive brands tend to have lower overrun.

Sherbet

In addition to sugar and fruit, sherbet contains a small amount of milk or cream to give it a smoother texture.

FAT CONTENT **1%**

OVERRUN **n/a**

Sorbet

Sorbet contains no dairy at all. It is made from water, sugar (or other sweeteners) and flavourings – usually fruit.

FAT CONTENT **0%**

OVERRUN **n/a**

Frozen yoghurt

Frozen yoghurt is made in a similar way to ice cream but contains yoghurt cultures and has a higher sugar content.

FAT CONTENT **0.5-3%**

OVERRUN **50-60%**

Soft serve

Soft serve ice cream contains less milk fat, which helps make it lighter and fluffier than standard ice cream.

FAT CONTENT **3-10%**

OVERRUN **30-60%**

Gelato

Gelato contains more milk than cream and less air than standard ice cream because it is churned more slowly.

FAT CONTENT **3-8%**

OVERRUN **20-30%**

Ice cream

Standard ice cream contains more cream than milk and is churned quickly to incorporate air into the mixture.

FAT CONTENT **10-20%**

OVERRUN **20-100%**

Cleaning the blood

Dialysis machines are artificial kidneys, keeping the blood clean when the kidneys fail

The kidneys have lots of jobs, but one of the most important is keeping the blood clean. Packed inside these bean-shaped organs are hundreds of microscopic filter systems. Blood passes in through the renal arteries at high pressure, rushing into balls of leaky blood vessels. Fluid and waste squeeze out of the bloodstream and into tiny tubes called nephrons. As the fluid passes through these tubes, the body reabsorbs useful molecules. The rest forms urine and is removed via the bladder.

This system is sensitive to damage. High blood pressure, diabetes and recurrent infection can stop the filters working. Should this happen, then dialysis can take over the job, allowing the kidneys to heal or keeping the blood clean until a transplant becomes available.

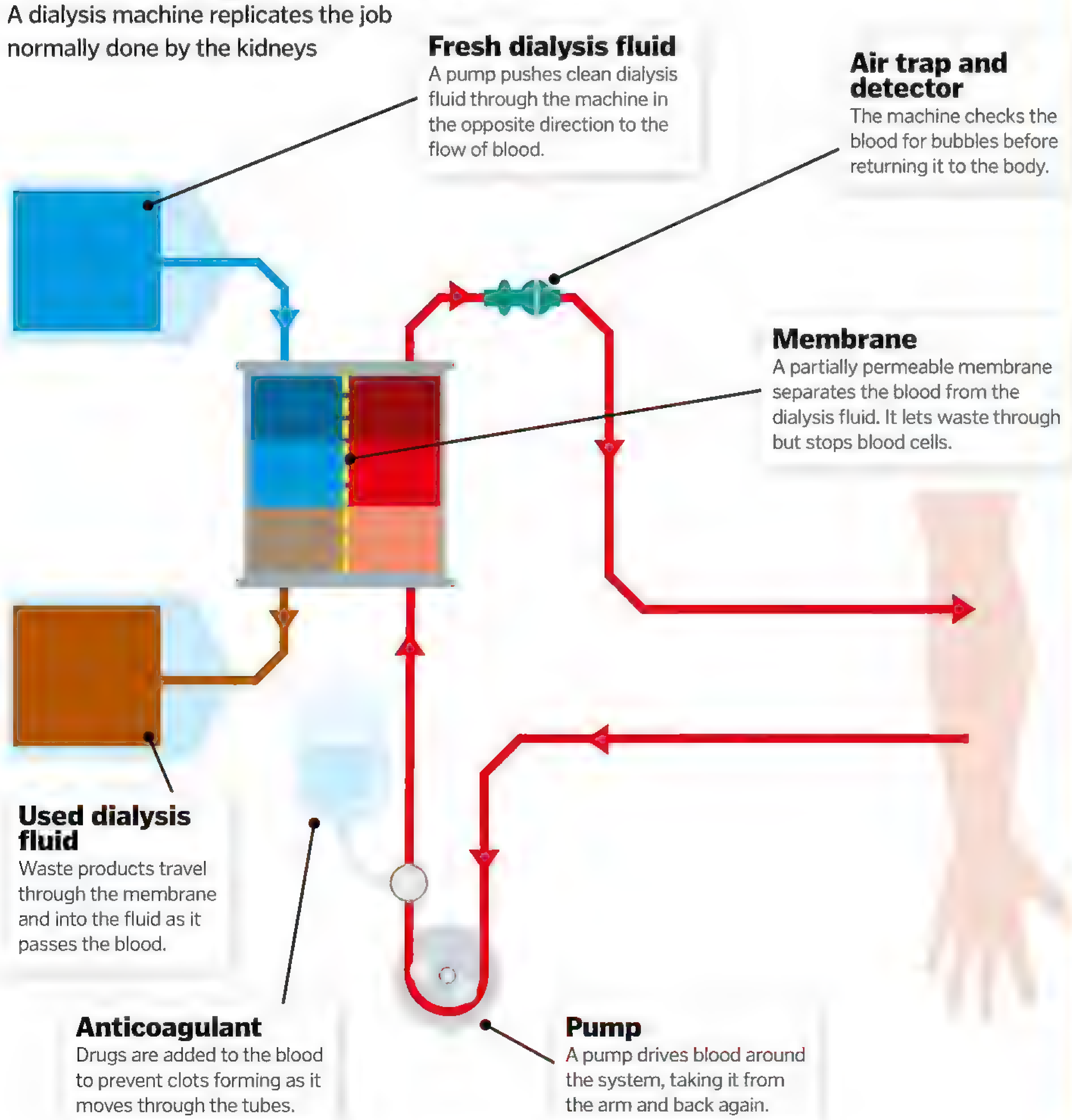
First, doctors widen the blood vessels in the arm by creating an arteriovenous fistula, or by implanting a graft. This joins an artery to a vein, allowing blood to flow quickly in and out of a haemodialysis machine. These machines are essentially artificial kidneys, and they clean the blood in almost the same way.

Blood enters the machine and passes over a semi-permeable membrane. Dialysis fluid passes in the opposite direction on the other side. The concentration of waste is higher in the blood than it is in the fluid, so the molecules diffuse across. However, the holes in the membrane are too small for blood cells, so they remain in the bloodstream and return to the arm. The whole process takes around four hours and patients need to repeat it three times a week.

The machine cleans the blood as it moves out of the arm and back again

How dialysis works

A dialysis machine replicates the job normally done by the kidneys



Peritoneal dialysis

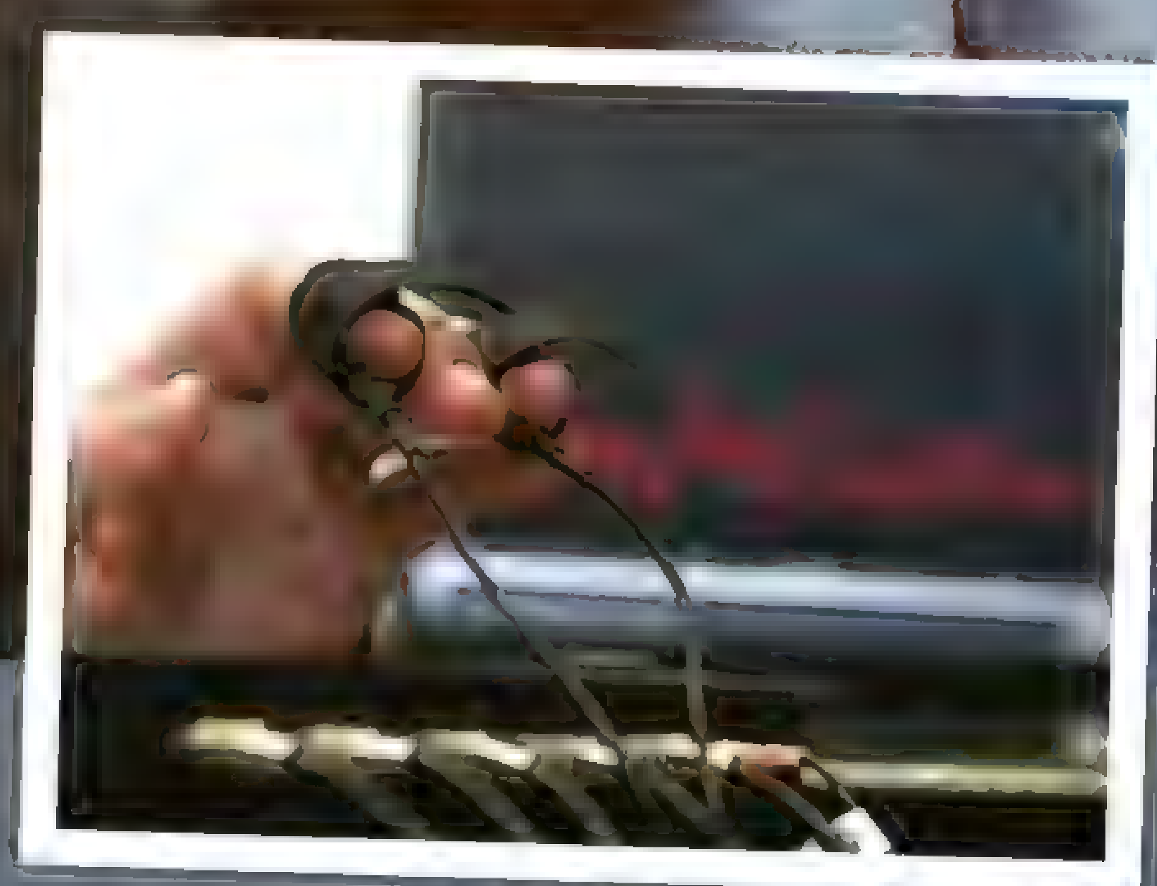
Passing blood through a machine isn't the only way to clean out toxins. Dialysis works by drawing chemicals out of the blood, through a membrane and into waste fluid, and this is possible inside the body too. The peritoneum is the membrane that lines the abdominal cavity around the digestive organs. It has lots of blood vessels and can work as a dialysis filter. To set this up, doctors place a small tube, or catheter, near the belly button, allowing dialysis fluid to enter the belly. As blood travels through the peritoneum, waste products pass across the membrane and into the fluid. The fluid can then be drained away, taking the waste out of the body with it. Peritoneal dialysis happens between four and six times a day, and people can do the fluid exchange by hand in their own homes.

Fluid enters the abdomen through a catheter near the belly button

WHY DO WE LIE?

It's not just bad behaviour – deception is a product of evolution and it gives your brain a real workout

Words by **Charlie Evans**



Polygraphs, also known as lie detectors, monitor a person's breathing rate, pulse, blood pressure and perspiration to try to determine if someone is lying

Your dog really did eat your homework, and you have no idea who took the last biscuit from the sweet jar. Lying is in your nature, but don't worry – it's in the nature of most humans. It's a technique that has evolved over billions of years, so it turns out you might not actually have that much to feel bad about.

Humans are social creatures, and that's something we have our giant brains to thank for. They evolved to be so large because we needed the extra space to be successful at communicating with others and keeping our social group happy. This has a lot of advantages. If you can build bonds with other humans you can access more resources because your friends and family will share food and shelter, helping you out when you need it. But to keep these close connections, sometimes we need to lie. Throughout hominid history it has been a genetic advantage to be a good liar, as it supports social bonds, and therefore you are more likely to survive and pass on your genes. Bending the truth, playing fast and loose with the facts, telling a tall tale - whatever you call it, lying is something that most individuals in our species find really easy.

Although deception is frowned upon by society, it actually evolved as a way to fine-tune our social skills and strengthen our relationships. Have you ever told a friend that you really loved the dinner they had cooked for you? Or maybe you've lied to your mum about accidentally breaking something in the kitchen? That's these evolutionary mechanisms kicking in, and whether it was to protect your reputation or just avoid upsetting someone, it probably worked well to protect your relationships (if you didn't get caught, that is).

YOUR BRAIN ON LIES

Lying is a creative task, and it's much harder for our brains than just telling the truth as it requires remembering lots of different information to keep the story consistent. Even more complicated is our ability to lie to ourselves, an extreme level of deception that

When do we learn to lie?

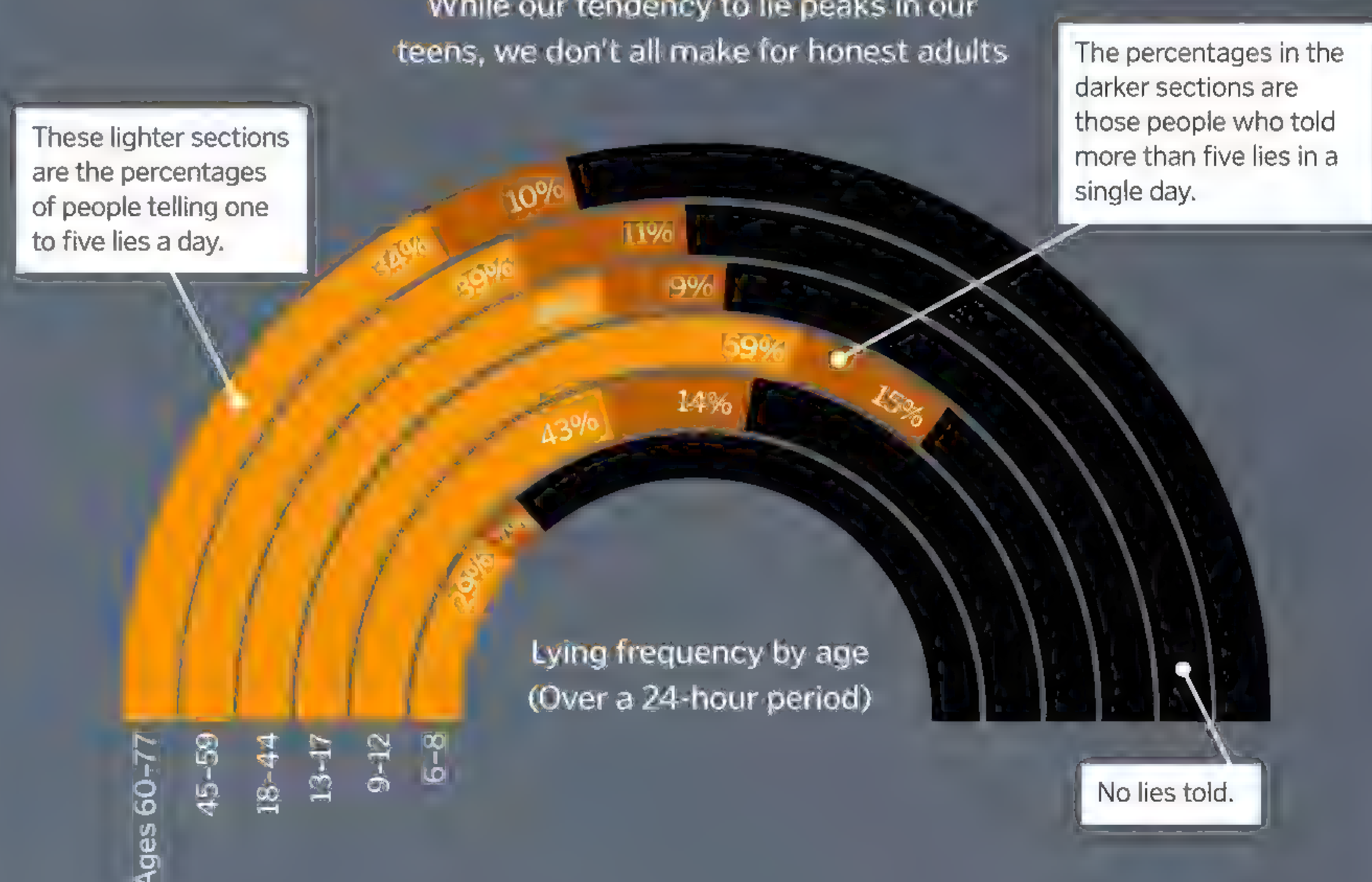
It's thought that we learn how to lie much younger than we probably think, with some research suggesting it may have begun as early as six months old. Over the years we perfect the art, and some estimates suggest by the time we are in college we may be lying to our mothers once every five interactions.

The developmental model of lying was first proposed by researchers Victoria Talwar and Kang Lee. Their work shows that children between the ages of two and three start telling primary lies – basic deceptions to cover up mistakes or bad behaviour – but without considering whether the listener will actually believe the lie. Around the age of four children start to tell secondary lies, more crafted and complex lies that are more believable. By age seven or eight children start telling tertiary lies, using consistent facts and follow-up statements. This is an ability that will stay with them for the rest of their lives.

Learning how to play games that involve a level of deception is often a vital step in learning to navigate deception as a social tool

Lying is a matter of age – honestly!

While our tendency to lie peaks in our teens, we don't all make for honest adults



requires keeping two pieces of information in our heads and ignoring one.

Whatever reason you are lying, and however complex the lie, there are three main parts of the brain that you use when you are being deceptive: the anterior cingulate cortex, which is responsible for monitoring errors, the dorsolateral prefrontal cortex which controls behaviour, and the parietal cortex, which processes information from your senses. These parts become more active when lying, and they can be seen using functional MRI scanners – a much more advanced version of a lie detector.

However, we've not always had the technology to help us detect a liar. For most of history we have relied on our observation and social skills. We learnt how to monitor other

people's behaviours for signs they were not telling us the truth; unusual eye contact, signs they might be sweating more, elaborating on a story with details that just don't sound believable. As our ability to lie evolved, so did our ability to detect a lie. This has come in helpful because not every lie is told because we want to keep our friends. Sometimes lying is used to manipulate others for personal gains, such as scamming people out of money. Being able to detect a lie is helpful for keeping our resources safe from people who are dishonest.

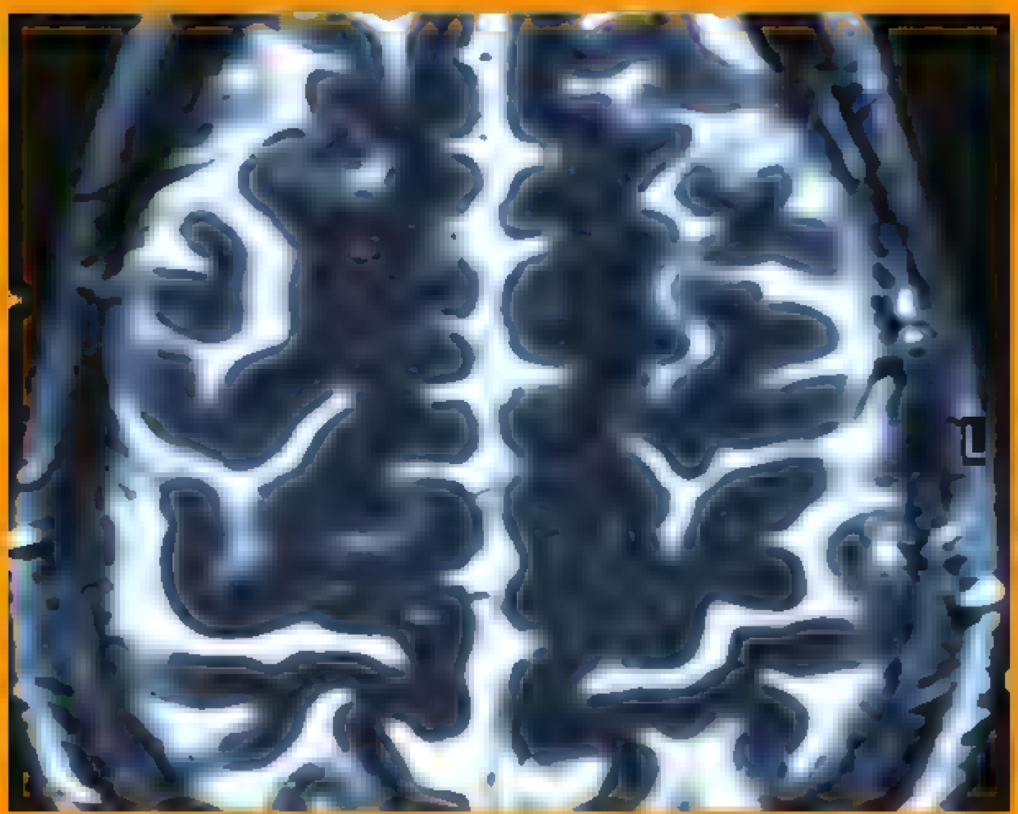
LYING IS NOT UNIQUE TO HUMANS

We're not the only species that has developed deceptive tactics. The skill has been mastered throughout the animal world, notably by tufted capuchin monkeys, which will shout out false alarms to scare away older individuals from food, and the polka-dot wasp moth, which mimics the same clicks of the bad-tasting delicate cycnia moth to ward off predators. These animals developed these tactics to protect themselves rather than strengthen social bonds.

Pathological liars

Pathological lying is a term that refers to the act of lying so naturally and instinctively that the individual finds it easier than telling the truth. Sometimes they can even believe their own lies. It is a condition that can be damaging to the lives of the sufferer as it destroys careers and relationships.

Neurologists have discovered that there are physiological differences in the brains of pathological liars, who have 22 to 26 per cent more prefrontal white matter and approximately 14 per cent less grey matter. It's thought that this difference means pathological liars are more able to make connections between different memories and ideas. However, it is unknown if the increased white matter is the cause of pathological lying or if the practice of frequently lying can cause structural changes in the brain.



It's grey matter that helps us to control our impulse to lie to others

How to catch a lie

It's all in the body language

1 Intense eye contact

Eye contact usually suggests honesty, and it is tempting for someone telling a lie to break eye contact. As a result, they will start making more eye contact than usual to overcompensate.

2 Contrary confirmation

Informal language and phrases that express they are being honest (such as 'believe me' or 'to be totally honest') hints that someone might not be telling the truth.

3 Frozen upper body

People tend to move less when they are being deceptive, gesturing with their hands less frequently and sometimes completely freezing their entire upper body.

4 Prolonged eye closing

Usually, people will blink for between 0.10 to 0.40 of a second, but when someone lies they often have their eyes closed for longer than a second.

5 Head shaking

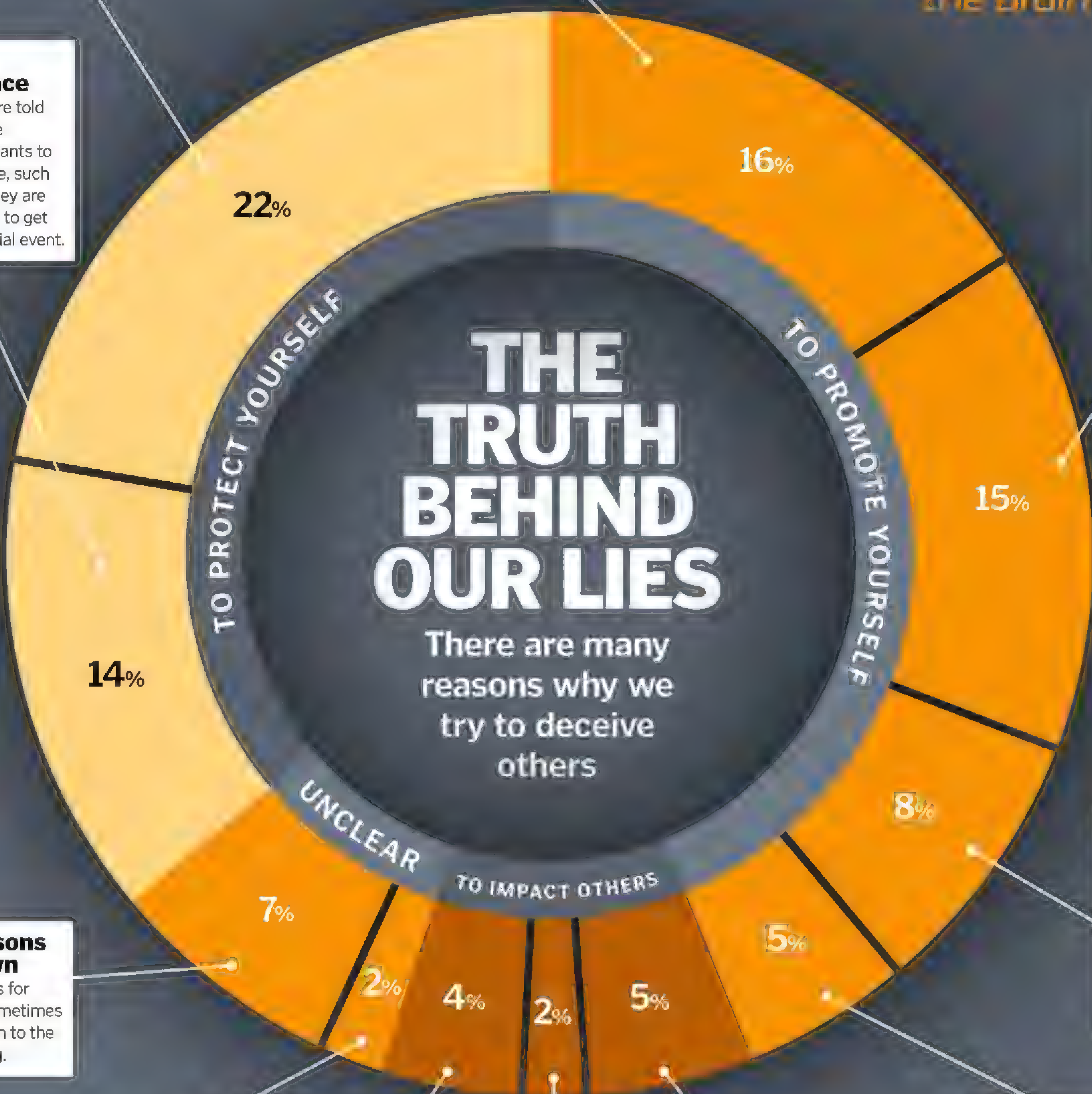
If someone says 'yes' but they shake their head 'no' at the same time, their body language might be giving away the real answer.

Cheating in a test could be an example of personal advantage or self-impression lying

THE TRUTH BEHIND OUR LIES

There are many reasons why we try to deceive others

"It is unknown if the increased white matter is the cause of pathological lying or if the practice of frequently lying can cause structural changes in the brain"



To avoid punishment
We have broken the law, made a mistake or committed a misdeed that we want to cover up.

For economic advantage
There is some financial reward, like a promotion or a pay rise that we will gain by telling this type of lie.

Social avoidance
Some lies are told because the individual wants to avoid people, such as saying they are sick or busy to get out of a social event.

For personal advantage
We are seeking a non-financial reward, such as affection, attention or higher social status.

To give a good impression
We want to shape a positive image of ourselves so lie about our character, saying we speak another language or that we're an excellent cook.

For reasons unknown
The motives for lying are sometimes unclear even to the person lying.

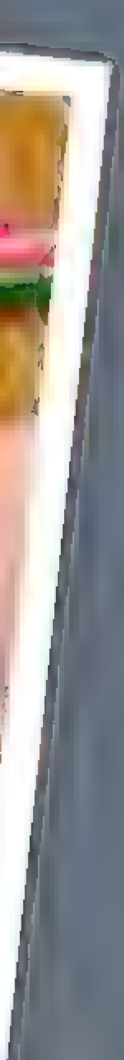
For humour's sake
Some lies are told for the purpose of making other people in our social group laugh, such as exaggerating a story or making up a funny anecdote that did not happen.

No real reason
Pathological lying is a condition where an individual compulsively lies to excess, often serving little or no purpose.

To fit in
Some deception comes from a desire to uphold social roles or avoid being rude in an attempt to fit in with the social group.

Malicious lying
Hurting other people by lying to them is known as malicious lying and serves to put other people down. This is sometimes done as revenge or to cover the liar's own insecurities.

Altruistic reasons
We might lie selflessly for the benefit of other people, such as offering reassurance or complimenting them to make them feel better.



Organ donation

Discover the science behind the surgical swaps that save lives

It's often a misconception that those who require an organ transplant have in some way damaged their own body, for example by smoking or drinking excessive alcohol. In some cases, genetics play a cruel role in the development of certain conditions, such as cystic fibrosis, meaning that transplants become the only treatment option. There are two main branches of the transplant process: organs donated by a living person, or those from a donor who has been declared brain dead.

Living donors can obviously only donate organs that they can live without, such as a single kidney or part of their liver. However, vital organs such as the heart and lungs are recovered from a patient whose brain has irreversibly lost all function, known as brain death. Being declared brain dead could mean that vital organs are still viable and undamaged. In order to maintain their viability, a ventilator artificially pumps oxygen into the deceased patient's lungs. As the heart does not require the brain in order for it to beat, blood continues to circulate and deliver oxygen to the organs. These organs can then be removed by surgeons and transplanted into another patient who is a match.

Finding that match, however, can be a complicated undertaking and can differ depending on the organ. More than just a compatible blood type, factors such as tissue type, body size and the patient's condition severity can determine who receives organs.

Once a donor and patient are matched and the transplant surgery has been a success, an internal battle begins. Organ rejection can threaten the success of any transplant. This immune response occurs because a patient's system does not recognise the antigens (proteins) from the new organ. Instead, the new organ is viewed as a threat and the immune system attacks it. This can be prevented by trying to match a patient's blood as closely as possible to the donor's, and by using immunosuppressant medication to restrict the immune response.

From A to AB

The journey from diagnosis to donation and recovery

Immunosuppressants or anti-rejection medicines bind to proteins that trigger the immune response and block them

Diagnosis

There are a whole host of conditions where a transplant is necessary to treat a patient. Coronary artery disease, diabetes mellitus and cystic fibrosis are just some of the conditions that could warrant a transplant.

Transplant

Once the heart has arrived, the surgeon will open up the patient's chest, remove the damaged heart and connect the patient to a heart-lung bypass machine to circulate blood. Once the surgery is finished, the new heart should start to beat with the flow of blood.

Recovery

During the process of physically healing, patients are monitored for infection or any signs of the organ being rejected by the body. Patients will have to take long term immunosuppressant medicine to help prevent their own immune system from identifying the new organ as foreign.

HUMAN ORGAN

Evaluation

After the point of diagnosis, a team of surgeons, nurses and coordinators will form a transplant team and carry out various tests to formulate the basis of what will result in a transplant match. In a living donation, the donor patient will go through several tests, both mental and physical, before they can donate.

Wait

Once on the transplant waiting list, patients will be notified if a match is found, which can be a lengthy period for many reasons. One is that organs have a limited time in which they can survive outside a living body, limiting the time frame of travel. For example, a kidney can last 24–36 hours, but a heart can only last around four to six hours.

Organ recovery

A team of surgeons will open up the deceased patient to extract the organ. In the case of a heart transplant, blood vessels are clamped and a heart preservation solution (HPS) is added before the vessels are cut and the heart is removed.

Preparation

Once an available match is found, the transplant team will evaluate the patient's suitability for surgery in a short time frame. With living donations of kidneys, cross-matching is carried out right up to the surgical procedure, which tests the immune response when blood from the donor and recipient are mixed.

Organs are put on ice after recovery and placed in a box designed to retain a cool temperature during transport to the recipient

Transplants through time

A history of the first successful human-to-human organ transplants

1954 Kidney

From one twin to another, Joseph E Murray and his team successfully transplant the first kidney.

1967 Liver

A team led by Dr Thomas Starzl perform the first successful liver transplant at the University of Colorado, US.

1967 Heart

Surgeon Dr Christiaan N Barnard performs the first heart transplant at Groote Schuur Hospital, Cape Town, South Africa.

1983 Lung

The first single lung transplant is performed at Toronto General Hospital, Canada, by a transplant team led by Dr Joel Cooper.

In 2016 there were

78,519 kidney

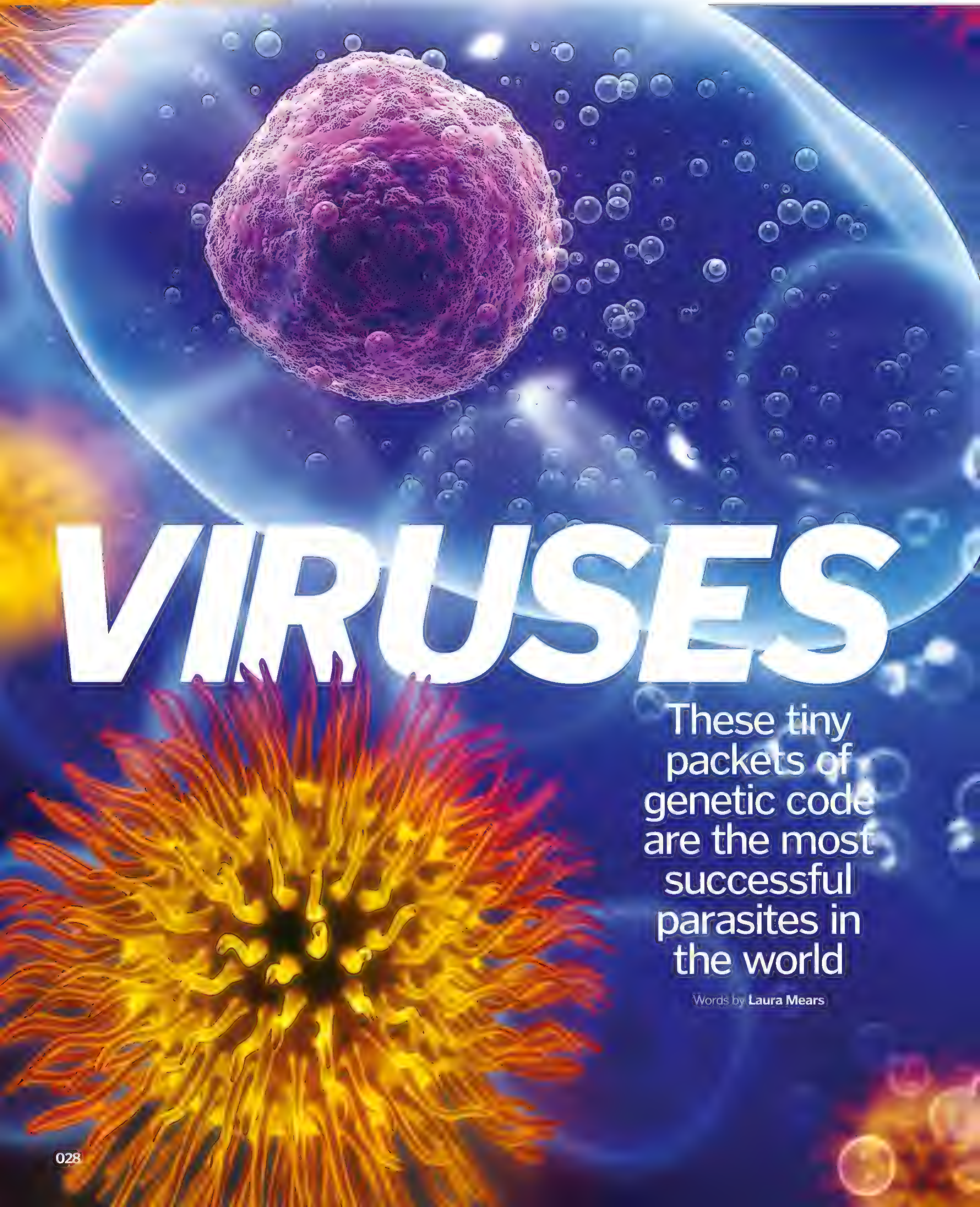
27,218 liver

7,457 heart

5,432 lung

transplants globally*

*Data from the WHO-ONT Global Observatory on Donation and Transplantation. Correct as of 24 May 2018



VIRUSES

These tiny packets of genetic code are the most successful parasites in the world

Words by Laura Mears

Viruses are the tiniest biological replicators on the planet, roughly 100-times smaller than bacteria. Made from a small strand of genetic code and covered with a tiny protein shell, they can't 'live' on their own. In fact, scientists aren't sure whether they're even alive at all.

The cells of living organisms have their own molecular production lines. They make temporary copies of their genes and pump them through molecular machines called ribosomes. These read the genetic code and use it as a template to assemble proteins. The simplest living organisms need between 150 and 300 genes to make all the proteins they need to survive, but viruses get by on as few as four. They simply hijack other cells and turn them into virus factories.

Viruses are clever; they make up for their genetic shortfall by borrowing from the cells they infect. Viruses don't have their own ribosomes, so they feed their code into the machines of other organisms, taking over the production line. The infected cell stops making its own proteins and starts reading virus code and assembling virus proteins.

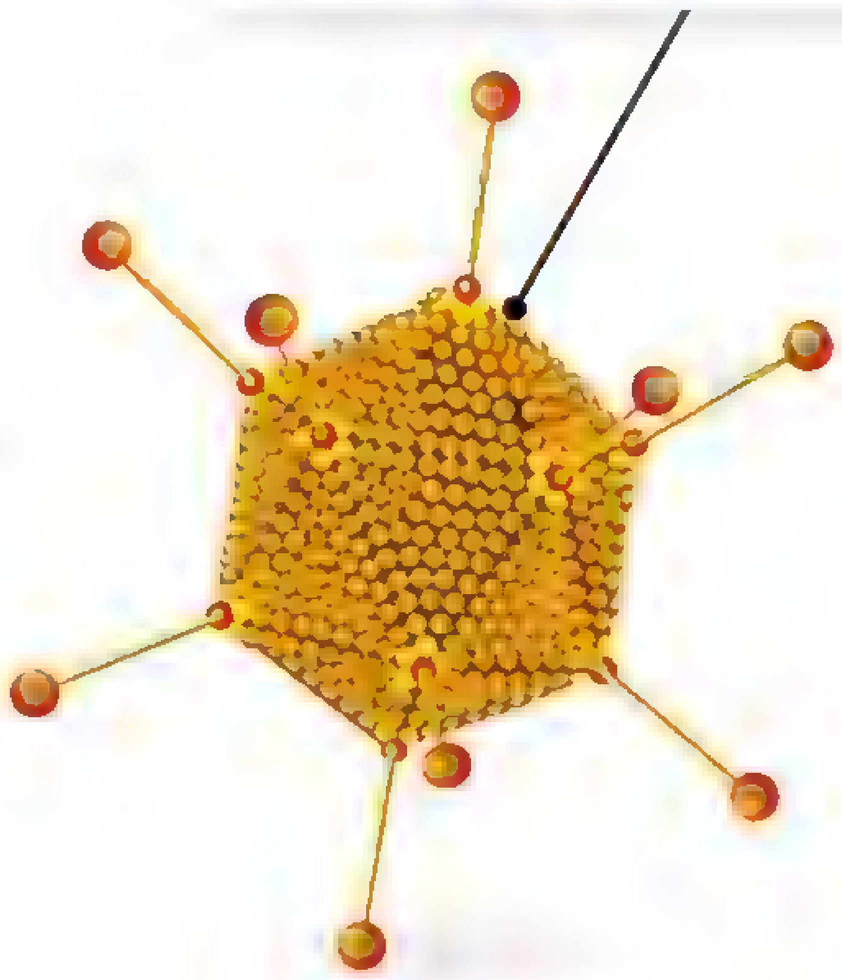
The core of a virus is its genetic code, which is stored in the same strings of biological letters used by living organisms. Some viruses have two strands of DNA like us, others get by with just one strand, and some carry their genes as RNA. This molecule is like DNA but with a different chemical letter, and it's used by living cells to make temporary copies of genes. Some viruses also carry the code to make an enzyme called reverse transcriptase, which allows them to convert RNA into DNA inside a living cell.

Genetic information is fragile, so to move from one cell to the next viruses need a way to protect their code. Some of their most important genes provide the instructions to build proteins that

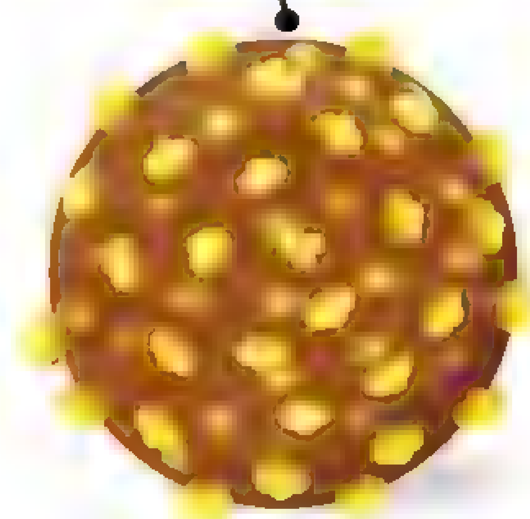
All shapes and sizes

Viruses may be small and simple, but they're very effective

Virologists use protective equipment to study human viruses in the lab



Polyhedral
The outside of these viruses is a regular 3D structure, most often a 20-sided ball.



Spherical
These viruses borrow membrane from the cells they infect, covering themselves in a fatty sphere.

Helical
The genetic code of these viruses is covered in a twisted tube-shaped coat.

Complex
These viruses have irregular shapes and do not fit neatly into the other categories.

"Viruses simply hijack other cells and turn them into virus factories"

Are viruses alive?

[illegible]

ALIVE

"Viruses use the same molecular building blocks as other living organisms: RNA, DNA and protein."

"Viruses evolve and have made complex changes to their genetics to adapt to their unique environments."

"Lots of other parasitic organisms depend on others for survival and cannot exist on their own."

DEAD

"Viruses have a protective protein coat, but they do not have a membrane and are not cells."

"Viruses don't use any energy when they're floating between cells. They simply exist."

"Viruses cannot copy their own genetic code – they need living cells to do it for them."

make a protective coat called a capsid. The capsid proteins form repeating structures that lock together to make a 3D shape. This crystal-like patterning means that viruses only need a few genes to make a complete shield. Icosahedral capsids, for example, often contain small triangles made from just three proteins. These triangles slot together to make a 20-sided ball that covers the viral genome.

The infectious packages of capsid and genetic code can survive outside of cells, but they can't replicate on their own. Known as virions, these virus particles need to get back into cells to continue their lifecycle. They do this by attaching to molecules on the cell surface.

Proteins on the outside of the capsid interact with proteins on the outside of the cell. This attachment may change the shape of the virion itself, allowing the particle to fuse with the cell membrane. Alternatively, it might trick the cell into pulling the virus into a membrane-covered sphere known as an endosome. Once inside, enzymes carried by the virion – or from the cell itself – break down what's left of the capsid, releasing the genetic code into the cell. The viral genome then enters the cell's production line and quickly begins manufacturing three main types of protein.

The first are enzymes that enable the virus to construct more copies of its own genes. The second are proteins that interfere with the cell's normal manufacturing processes. The third type are the structural proteins that work to build new virus particles.

When the new virus particles are complete, the virus needs a way to release them to infect more cells. 'Lytic' viruses simply burst out, releasing all their virions in one huge pop and killing the cell in the process. 'Lysogenic' viruses release new virions one by one, allowing the host cell to survive and reproduce. Some viruses even stitch their genetic code into the code of their host, so that every time the cell divides the new cells also get a copy of the viral genes. This allows viruses to remain inside cells for a long time, staying dormant and then reactivating later, a property known as latency.

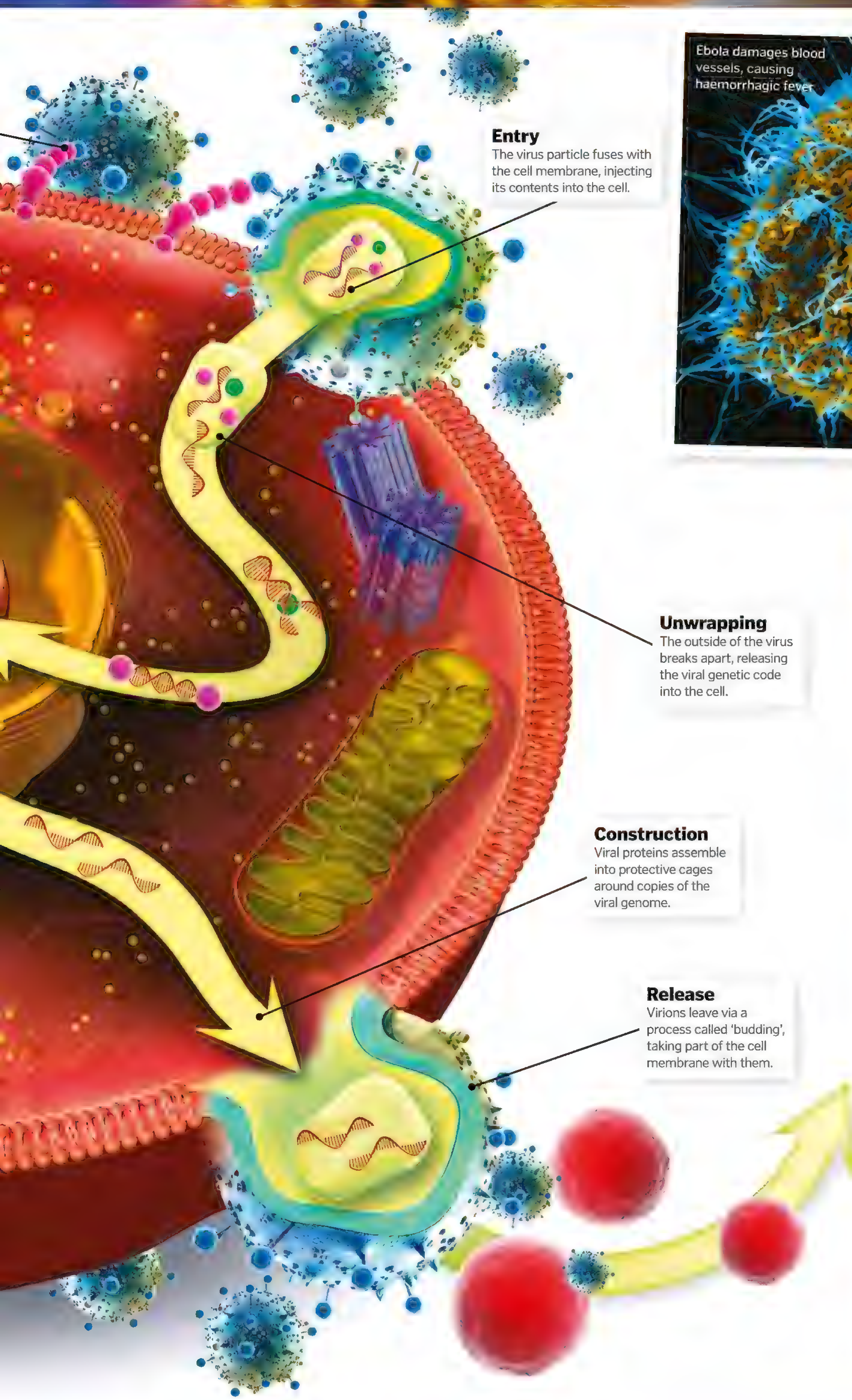
Cells do attempt to defend themselves from this type of attack. They destroy loose genetic code and send signals to the immune system to let it know about the infection. But, viruses have

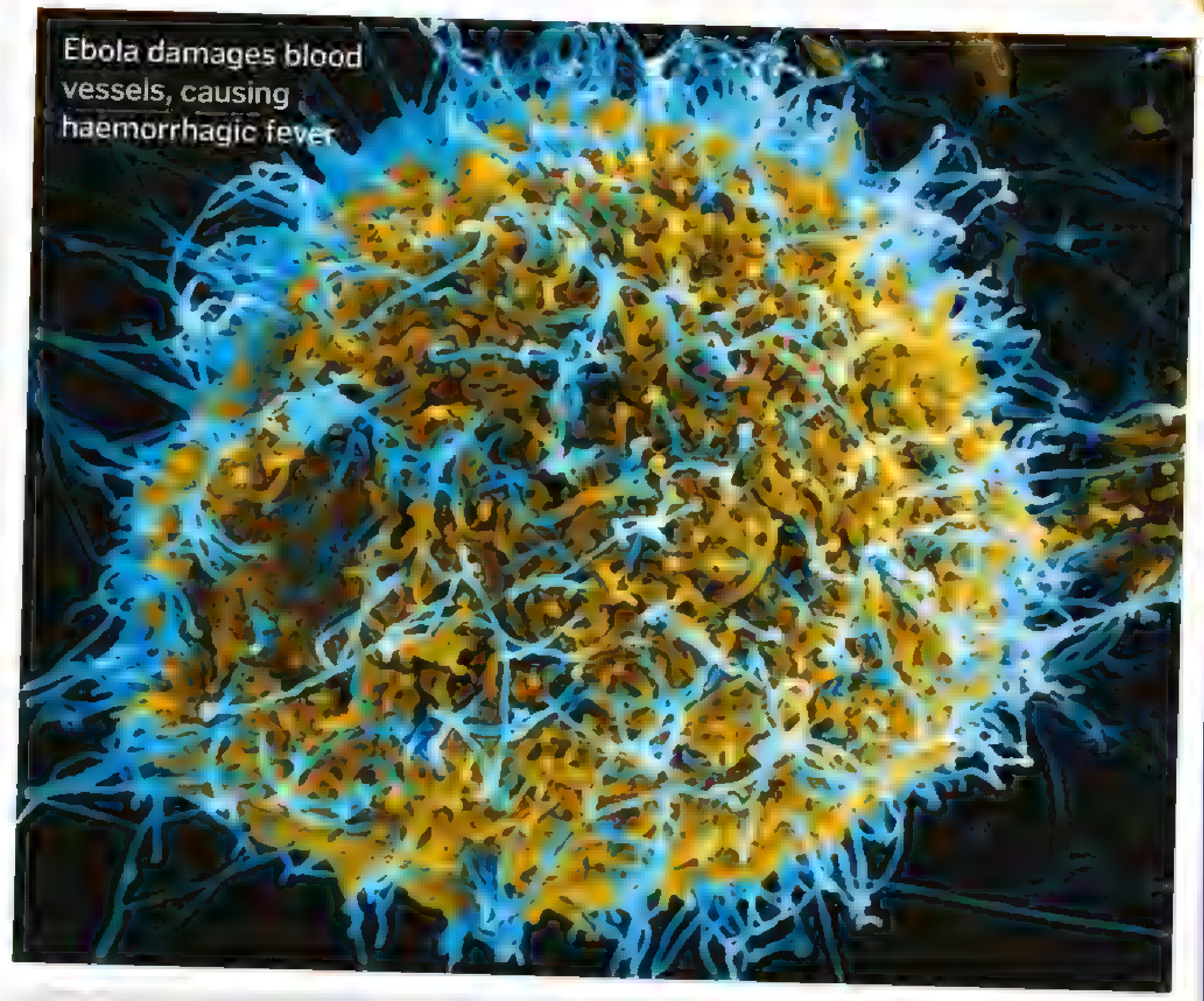
"Lytic viruses simply burst out, releasing all their virions in one huge pop"

Virus production

These pathogens turn cells into miniature virus factories

Below: the structure of an influenza virion




Ebola damages blood vessels, causing haemorrhagic fever

5 DEADLIEST VIRUSES

1 Ebola
Ebola causes haemorrhagic fever, killing an average of 50 per cent of people infected. The outbreak between 2014 and 2016 was the largest ever recorded.

2 Marburg
Carried by fruit bats, Marburg virus is fatal in around 50 per cent of cases. It's part of the same virus family as Ebola, both of which damage the blood vessels.

3 Crimean-Congo haemorrhagic fever
This virus kills up to 40 per cent of people infected, usually within two weeks. It's transmitted by ticks in Africa, the Middle East and Asia.

4 Coronaviruses
MERS and SARS are types of coronaviruses that cause a cough, fever and breathlessness. MERS kills up to 35 per cent of patients.

5 Nipah
Nipah virus first appeared in 1998. It's carried by fruit bats and causes fever, headaches, drowsiness and sometimes fatal brain swelling.

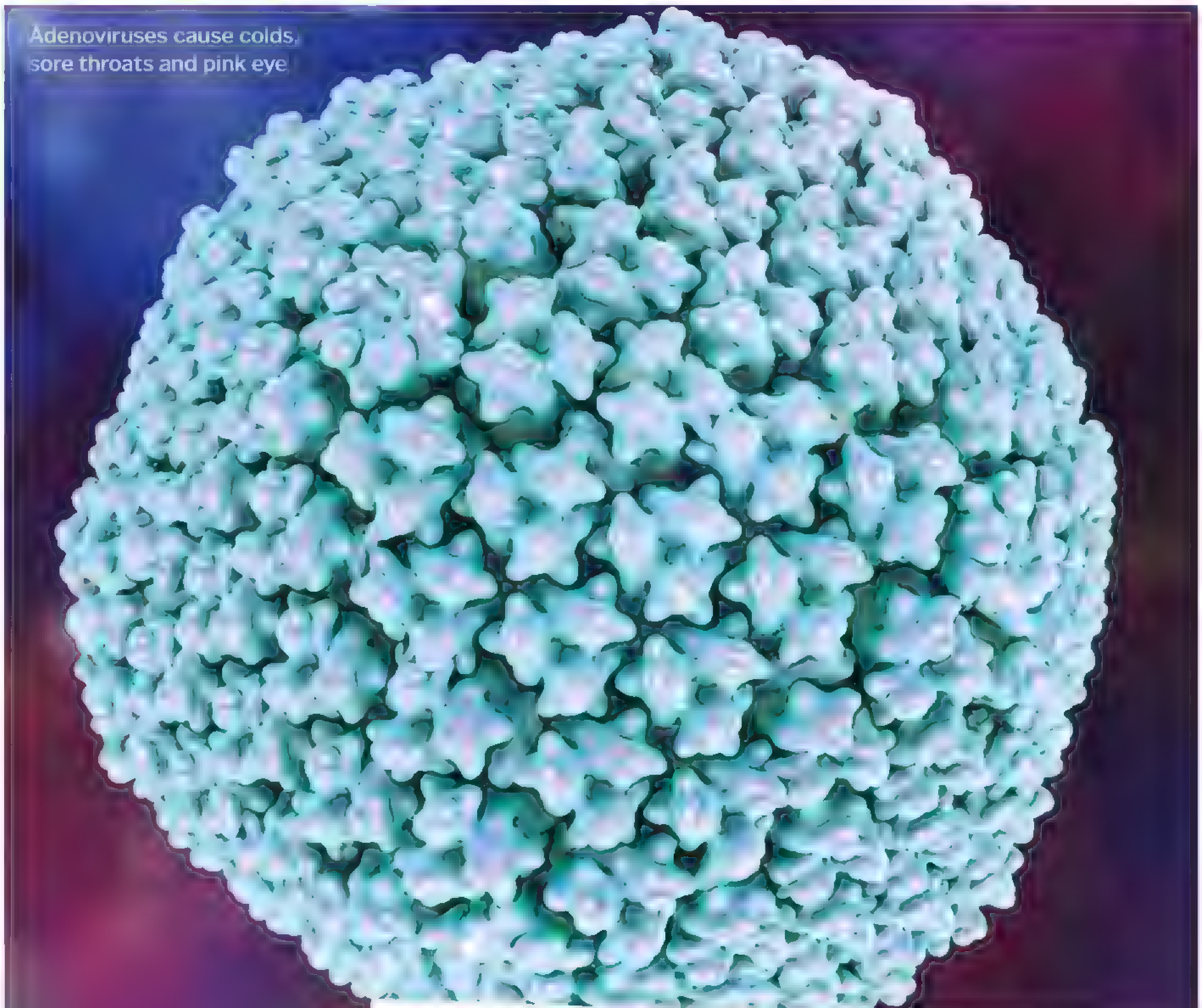
evolved ways to evade these defences. In the process, some have gained characteristics that harm their hosts, a property known as virulence.

Many viruses cause disease, diverting healthy cells away from their normal activities. The type of damage a virus does depends on the cells it infects, the way it interferes with molecular machines and the way it releases new virions. Some of the most serious problems arise when viruses infect immune cells, preventing the body from fighting back. Ebola, Marburg and HIV all harm the immune system.

However, viruses aren't all bad; infections help to shape the way our bodies work. Studies of the human genome have revealed that around eight per cent of our genetic code actually came from viruses. Known as 'human endogenous retroviruses', or HERVs, they are easy to spot because they still carry the remnants of three viral genes: gag, pol and env. These genes belong to retroviruses, which stitch their genetic code into the genome of their host.

Retroviruses leave a permanent mark on DNA, and the results of ancient infections have been passed from parent to child for thousands of years. Evolution has gradually changed the sequence of these leftover viral genes, making them unable to produce new virions. Our bodies have found new uses for the code left behind.

One HERV, HERV-W, codes for proteins that would once have sat in the outer envelope of a virus, helping it to fuse with cells. We have adapted the code to make new proteins that help to fuse cell membranes together to form the placenta. Without the leftovers of ancient viral infections we wouldn't be here today.

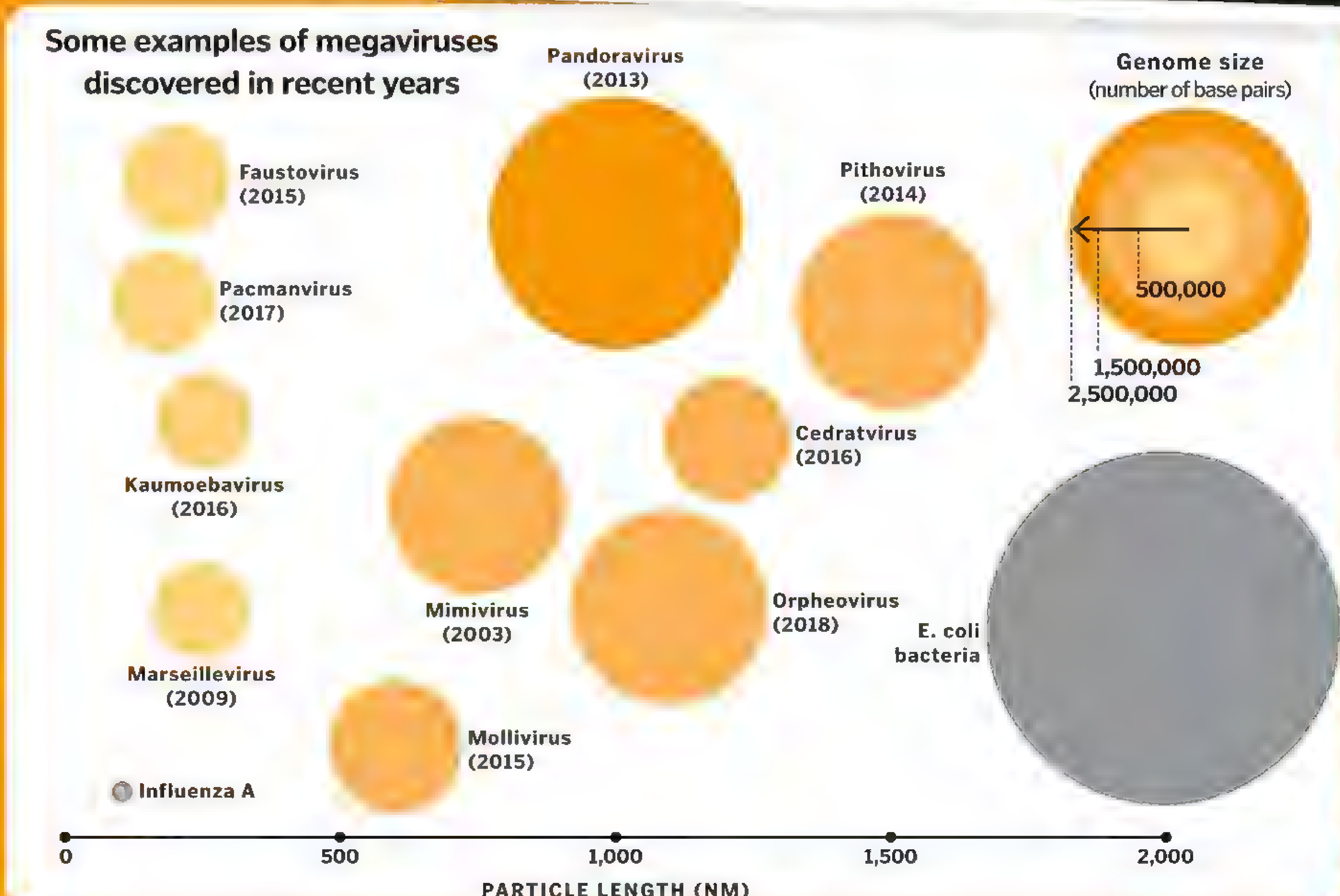

Adenoviruses cause colds, sore throats and pink eye


Bacteriophages inject their genetic code into bacteria cells, turning them into virus factories

The giants of the virus world

Viruses tend to have tiny genomes with only around 2,000 genetic letters. That's compared to around 3 billion in our own genome. They strip their genetics back to the bare essentials, and borrow everything else from the cells they infect. Even so, there are a few unusual 'megaviruses' that buck the trend.

Mimivirus has a bloated genome containing 1.2 million letters. It's so enormous that when researchers first saw it they thought it was a bacterium. Unlike most viruses, it carries genes for building proteins, suggesting that it may have evolved from an organism that could once fend for itself. An alternative hypothesis is that it stole the genes from the cells it infects.



Viral vectors

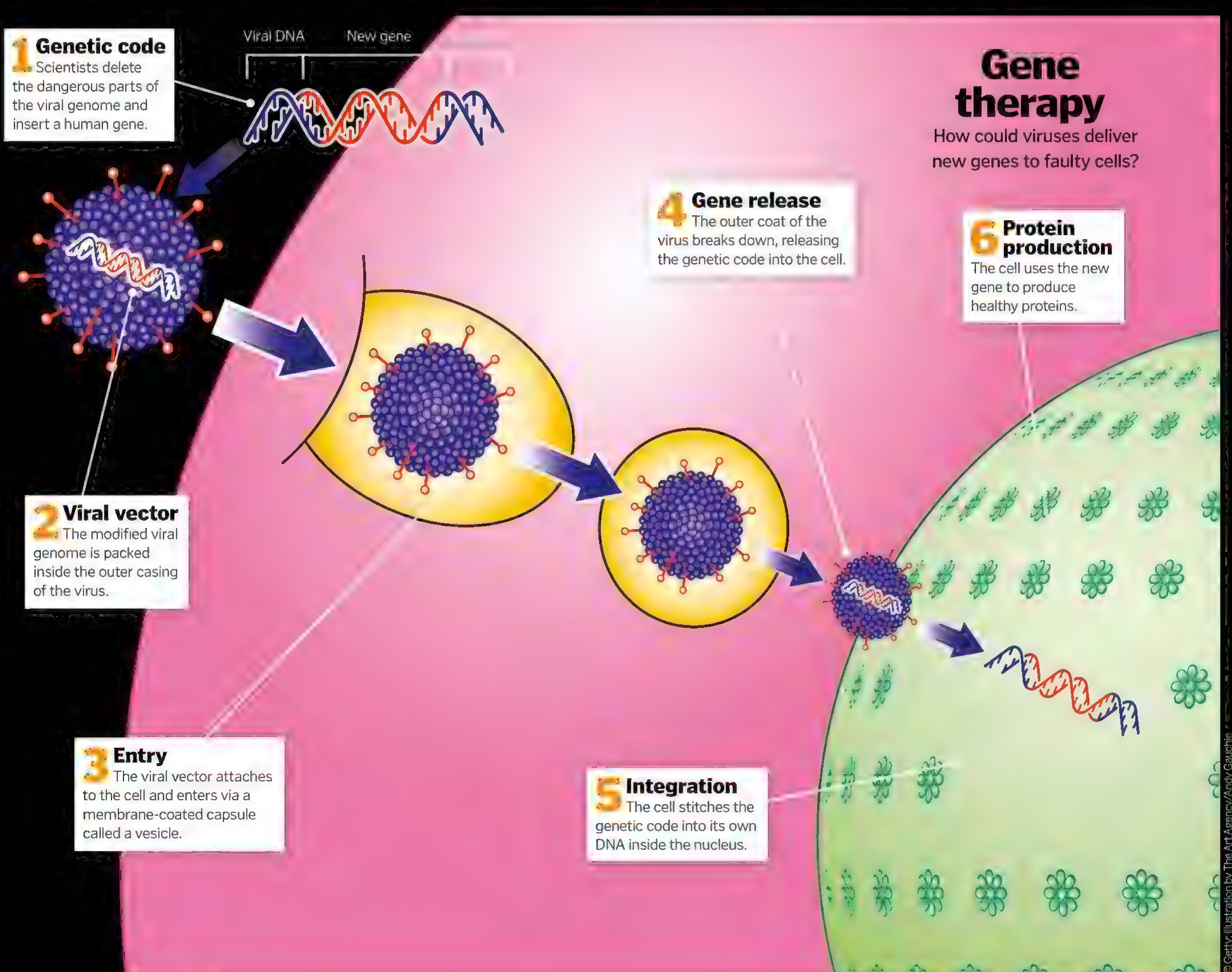
These tiny packets of genetic code are the most successful parasites in the world

Viruses specialise in getting past cellular defences to deliver genetic information into cells, but in nature they often contain genes that cause disease. However, if we strip out these damaging stretches of code we could use the outer virus packaging as a way to deliver useful genes to damaged cells. This is the idea behind viral vectors.

The first step requires scientists to delete the parts of the viral genome that allow viruses to make copies of themselves. Then they add the code for different genes. When the modified virus infects a cell it carries these new genes with it.

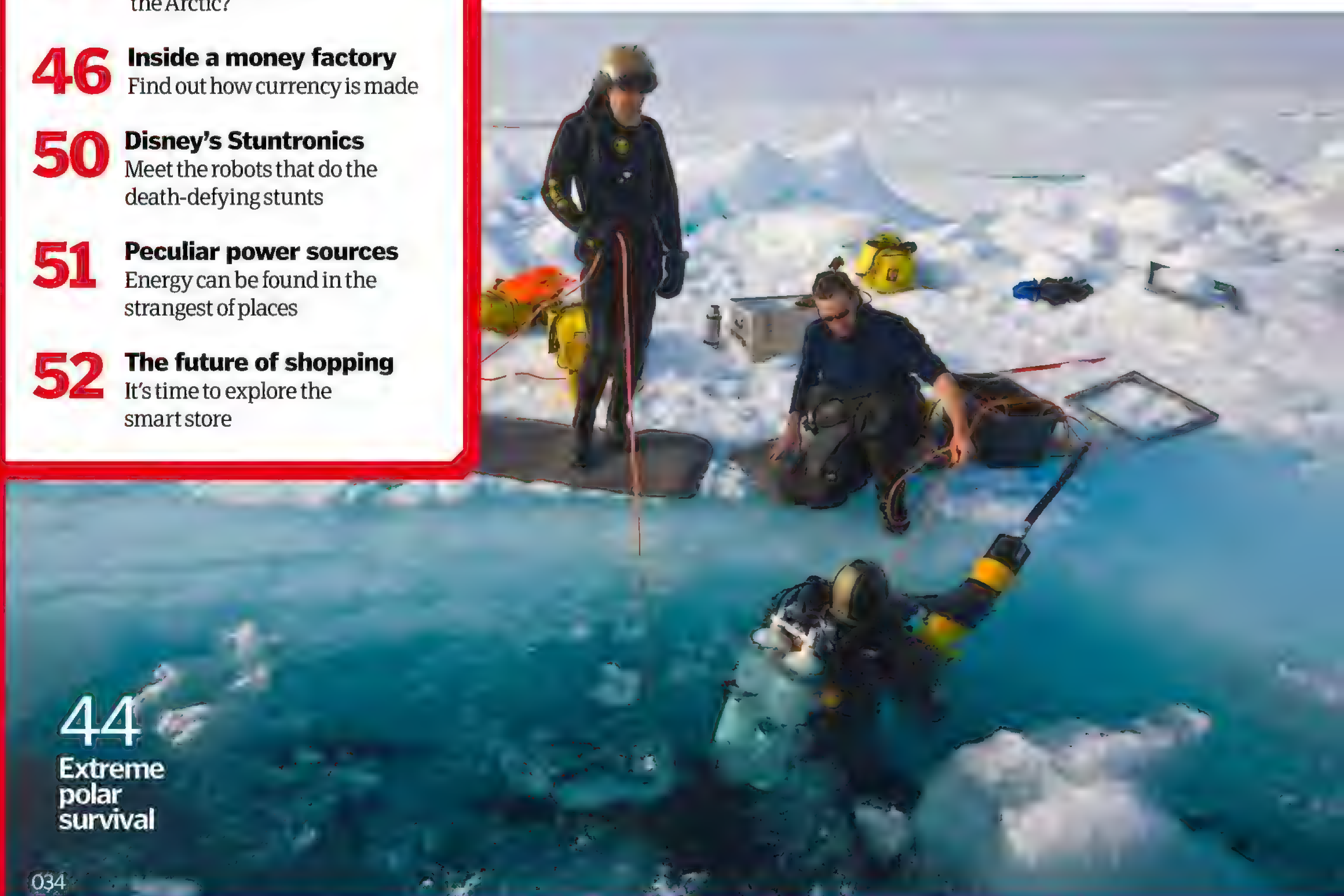
The most commonly used viruses for vector science are adenoviruses and retroviruses. Adenoviruses have a DNA-based genome and temporarily infect mammalian cells. The cells make viral proteins for a short time and then they go back to normal. Retroviruses are RNA-based and insert their genetic code into the genome of the cells they infect. This permanently changes the DNA of the cell, making it produce viral proteins forever.

In the lab, viral vectors allow scientists to find out what happens when cells gain the ability to make different proteins. Outside of the lab, viral vectors have the potential to fix broken genes by delivering fresh genetic code to human cells. However, the technology may be dangerous because it's hard to control exactly where the cell puts the new genes. Research is ongoing to find out if we can safely use viruses for gene therapy.

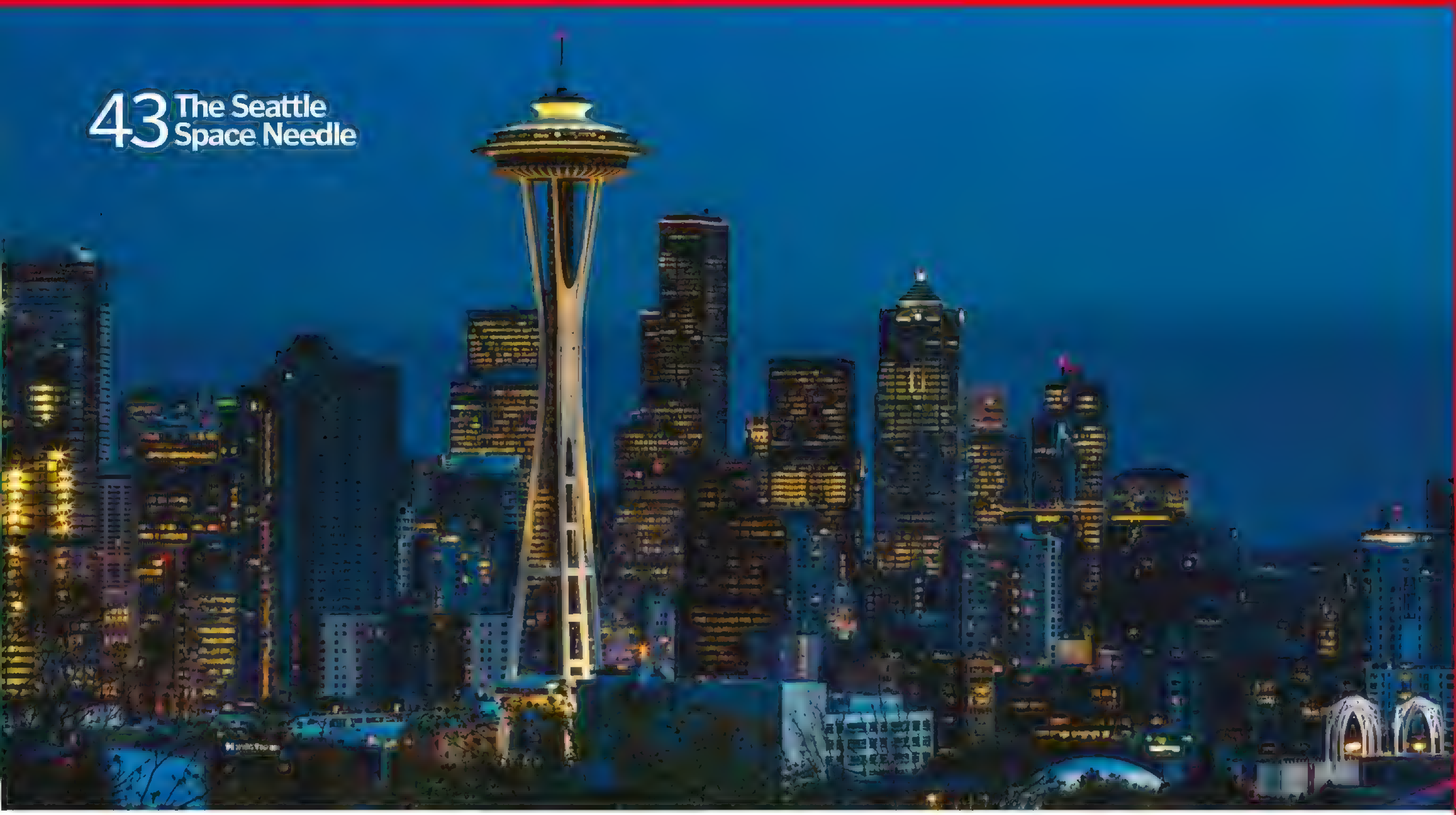


TECHNOLOGY

51
Peculiar power sources



44
Extreme polar survival


43 The Seattle Space Needle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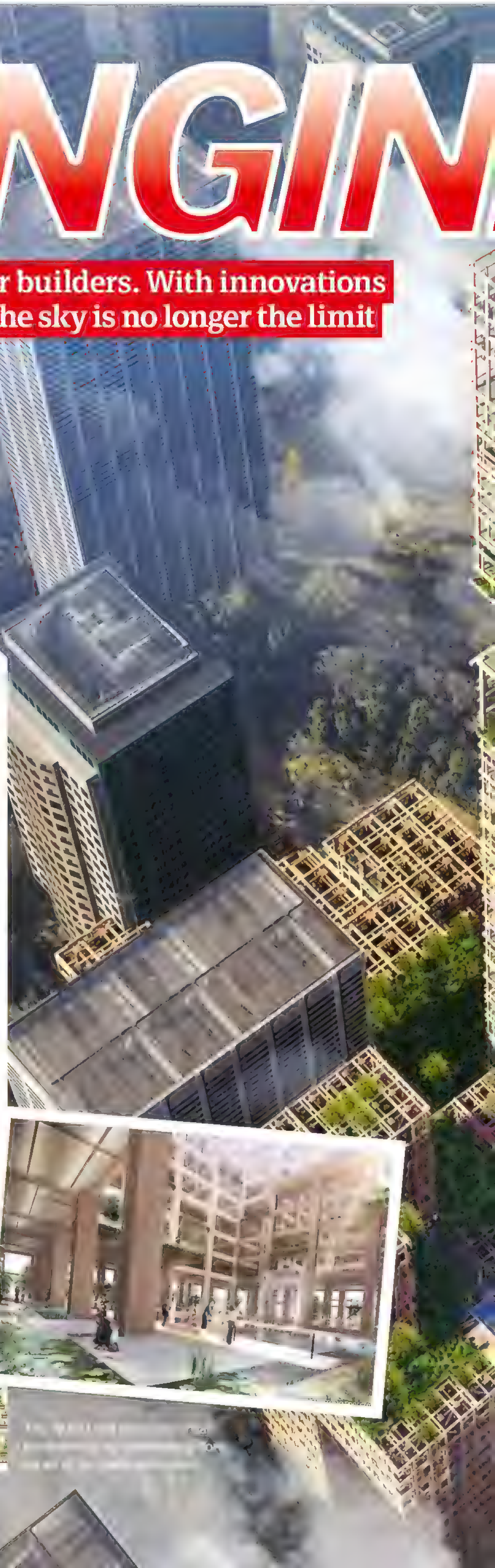
EPIC ENGIN

Behold incredible creations from the world's master builders. With innovations across the ocean, on land and deep underground, the sky is no longer the limit

Words by **James Horton**

SOARING STRUCTURES

Amazing architecture and innovative designs that enable us to defy gravity



W350 wooden skyscraper

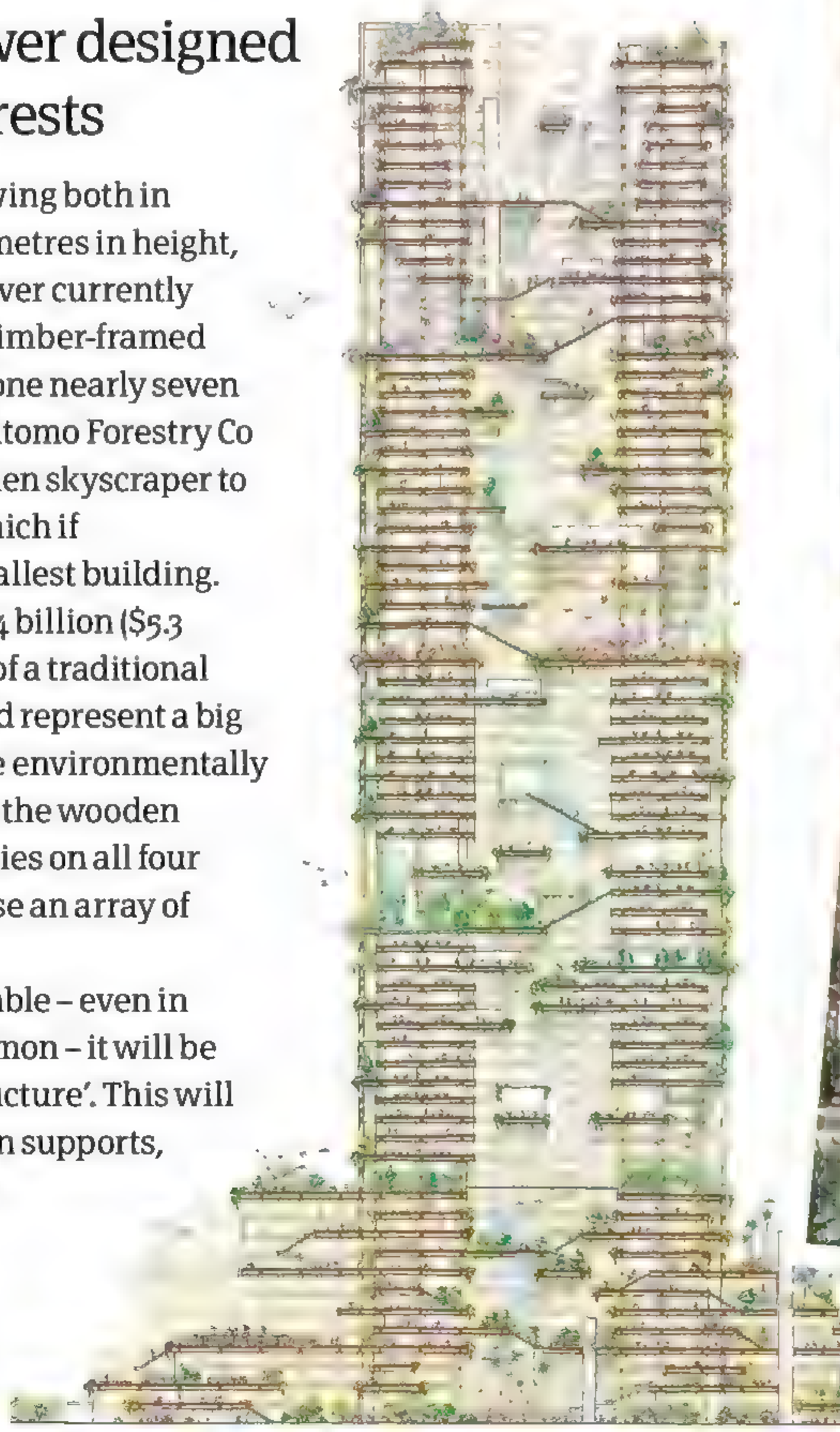
- **Location:** Tokyo, Japan
- **Progress:** Planning stages, completion target 2041

The timber-framed tower designed to change cities into forests

Tall wooden buildings are growing both in popularity and in scale. At 53 metres in height, a student residence in Vancouver currently holds the title of the world's highest timber-framed building, but Tokyo may soon boast one nearly seven times taller. Japanese company Sumitomo Forestry Co have proposed a 350-metre-tall wooden skyscraper to celebrate their 350th anniversary, which if commissioned will become Japan's tallest building.

With a predicted cost of just over £4 billion ($5.3 billion) – approximately double that of a traditional concrete skyscraper – the W350 would represent a big step towards Tokyo becoming a more environmentally friendly city. The organic aesthetic of the wooden structure will be bolstered by balconies on all four sides of the building, which will house an array of plant life.

To ensure the building remains stable – even in Tokyo, where seismic activity is common – it will be constructed using a 'braced tube structure'. This will involve a mixture of steel and wooden supports, with wood forming 90 per cent of the building's material.



The W350 will house shops, offices, residential units and a hotel

Beijing Daxing International Airport

- **Location:** Beijing, China
- **Progress:** Under construction, completion target September 2019

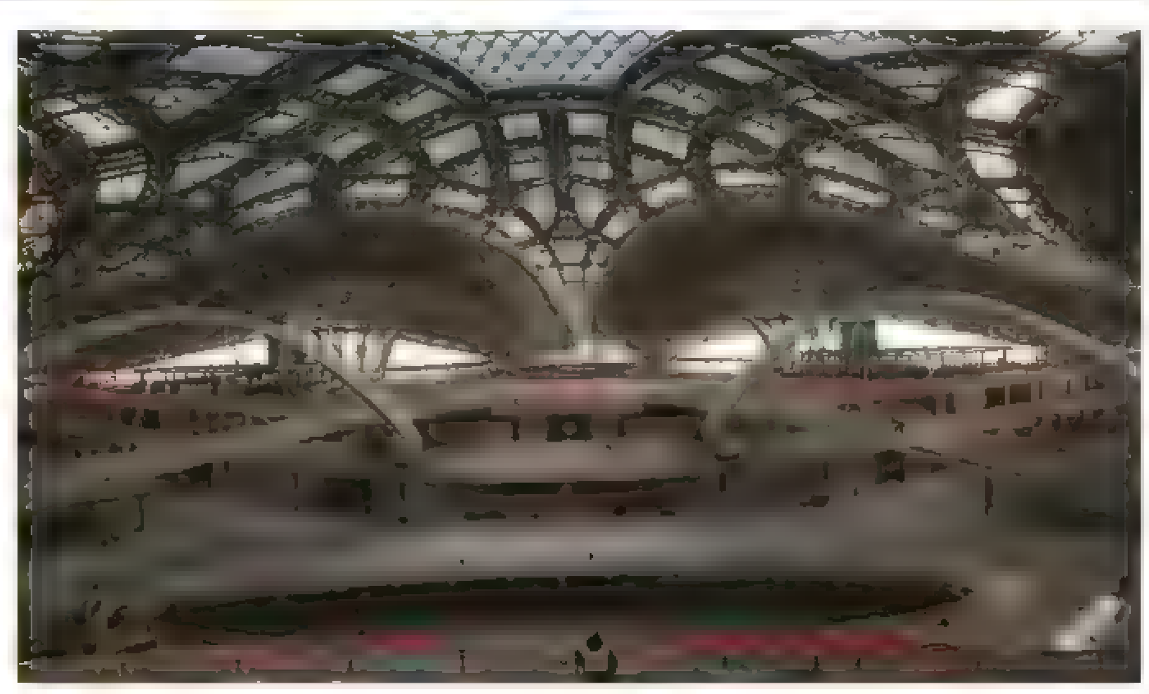
China's latest infrastructure project will cater for 100 million passengers every year

Despite its size, the People's Republic of China has a relatively low aviation capacity. The Beijing Daxing International Airport was proposed to improve this, and it's set to do so in a big way.

This gargantuan airport, designed in collaboration with Zaha Hadid Architects, will feature four runways at the time of its opening and an intricate, flower-inspired terminal space built using 1.6 million cubic metres of concrete and 52,000 tons of steel. In total, the new airport will encompass an area of 47 square kilometres, and it has rightly been described as a testament to China's world-leading production capabilities.

Initially, Beijing's new airport is predicted to transport 45 million passengers per year, but this figure is expected to grow to a whopping 100 million passengers, making it one of the busiest airports in the world.


By 2025 it is hoped that the airport will be able to accommodate 630,000 flights a year


When it opens in late 2019, the Beijing Daxing will be the world's largest international airport

GOING UNDERGROUND

With advanced tunnelling technologies, these projects are changing the infrastructure beneath our feet

Crossrail

- **Location:** London, UK
- **Progress:** Under construction, opens fully 2019 or 2020

The tunnels that represent the pinnacle of precision engineering

The Crossrail network was an ambitious undertaking, requiring eight tunnel boring machines to work 24 hours a day, seven days a week for three years. During that time the machines carved tunnels totalling 42 kilometres in length, but distance wasn't the only obstacle the Crossrail engineering team faced. To save on time and expenditure, the new tunnels ran as close as possible to their optimal path underneath London and came precariously close to existing infrastructure.

The machines had to avoid building foundations, sewers, utility tunnels and existing underground rail lines. Under the densely occupied underground of Tottenham Court Road, for example, the new tunnel came within one metre of an operational tube platform. Over 200,000 concrete segments were used to assemble the tunnel walls, and this structure was supplemented in places by additional sprayed concrete, which was used to reinforce the cross-passages that served to connect parallel rail lines.

Laser guidance
The machines are governed by a laser guidance system, which ensures the tunnel ends up within 1mm of its target destination.

Cutting wheel
The front face of the machine slowly revolves and carves away dirt using disc cutters and scraping tools.

Stabilising pressure
To prevent the tunnel face collapsing, dirt removed by the cutting wheel is collected behind its face to provide stability.

Providing thrust 1
Once the concrete segments have formed a stable wall, pistons are pushed against them to drive the cutting wheel forwards.

The Boring Company

- **Location:** Los Angeles, US
- **Progress:** Trials ongoing

The tunnel company with an incredibly ambitious goal – to beat a snail in a race

Tunnel boring machines are slow – so slow, in fact, that a soft-soil variant is 14 times slower than a snail. But the Boring Company's founder, Elon Musk, has laid down the gauntlet: he wants his machine to beat a snail in a race.

Designing a carving machine that digs over 14 times faster than a traditional one is no mean feat, but Musk has a few ideas as to how this can be done. Most importantly, by placing vehicles inside the tunnel on an automated electric skate network, the tunnel's dimensions can be reduced substantially. This paves the way for an automated shuttle system that's set to revolutionise city travel, and it could be coming soon.

Inside the Boring Loop network

1 Departure
Private vehicles – along with public transport vehicles carrying between eight to 16 passengers – would enter the tunnel network at designated entry points.

DID YOU KNOW? *The Boring Company has been selected to build a Loop network connecting downtown Chicago to O'Hare Airport*

Tunnel boring machines

The giant mechanical worms that create perfect tunnels and never need to rest

Crossrail's TBMs carved out approximately 3.4 million tons of earth over three years

Dirt removal 2
Clay, chalk, soil and other geological materials are carried away from the cutting face via a revolving screw mechanism.

Lock and key 3
Reinforced concrete segments are lifted into place via a mechanical arm. A conical-shaped keystone is added last to lock the segments in place.

Emisor Oriente water tunnel

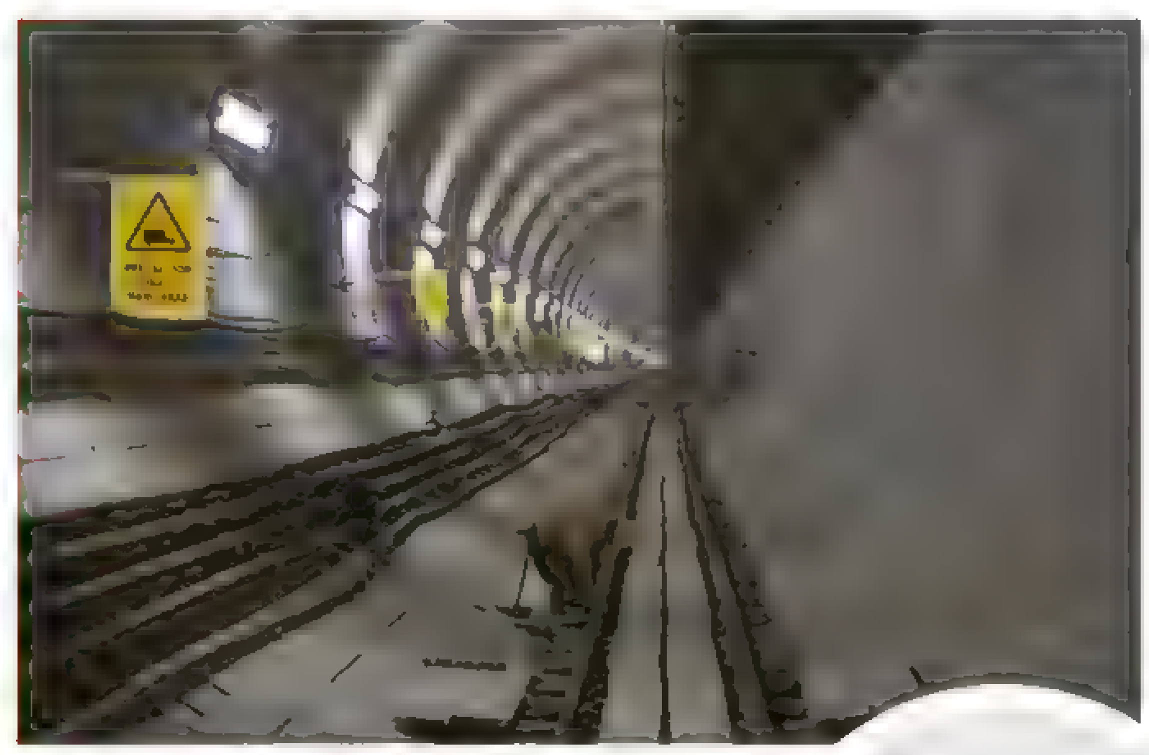
- **Location:** Mexico City, Mexico
- **Progress:** Completed and opened in 2018

The buried structure built to preserve Mexico City

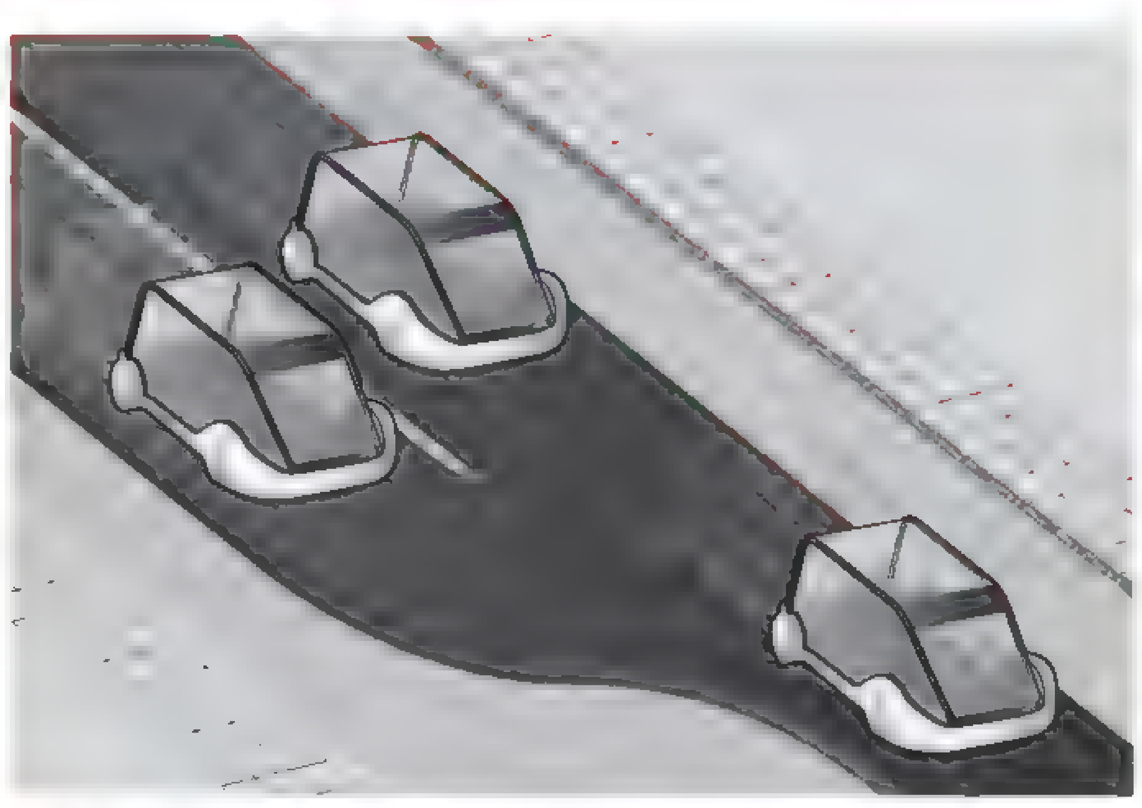
Sewers aren't typically seen as the most glamorous of constructions, but the Emisor Oriente wastewater tunnel performs an invaluable service for Mexico City.

The city's growing population has led to an increased demand for water, which is pumped from the lakebed that lies beneath it. However, this has resulted in the city filling the void where the water used to be. Mexico's capital is sinking – possibly by as much as 12 metres in the past 100 years – and is now vulnerable to flooding.

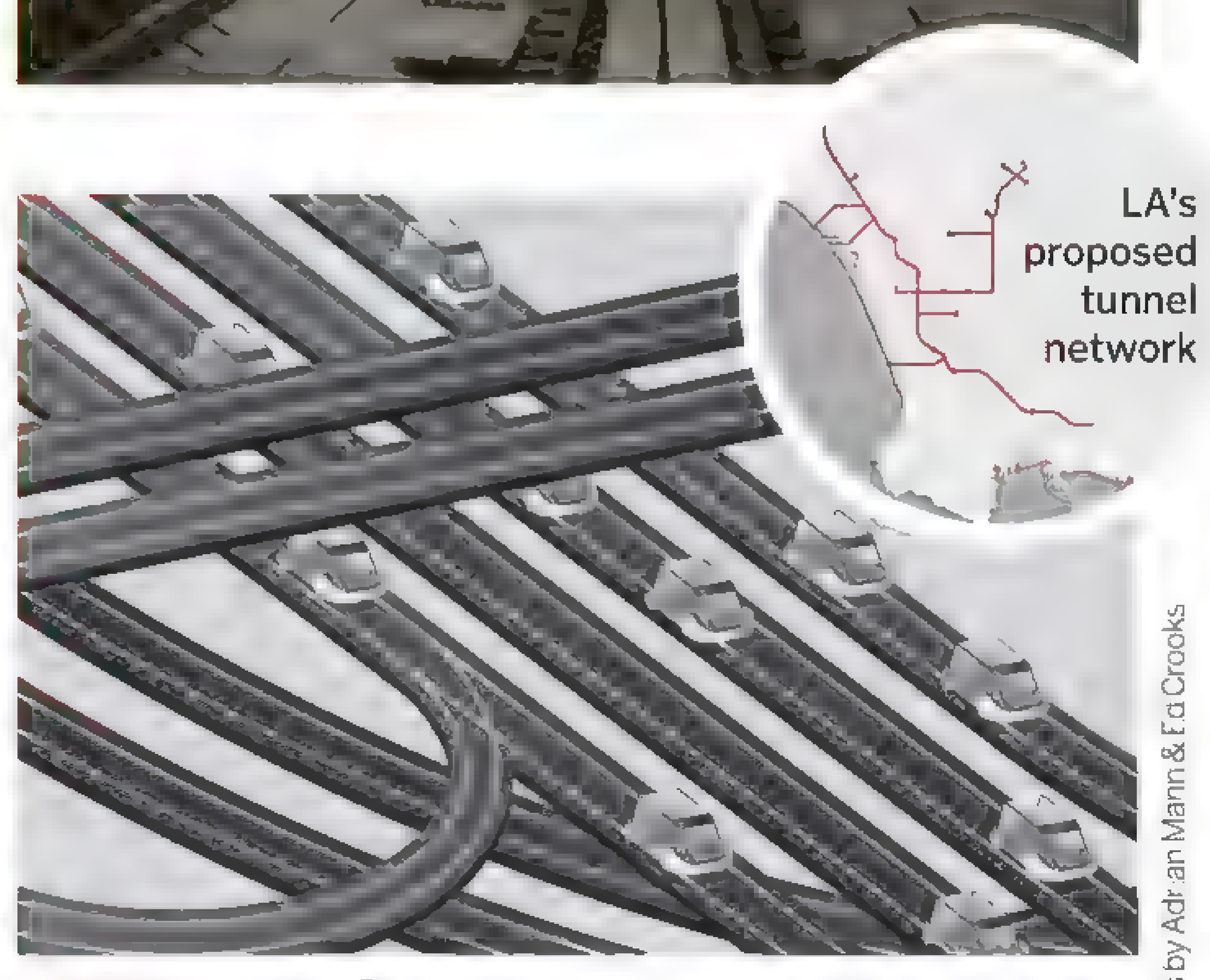
Fortunately, engineering innovation is on hand to help. The Emisor Oriente shifts rainfall and wastewater at a rate of 150 cubic metres per second through its 62-kilometre length. Carved using six custom-built boring machines equipped to deal with the complex ground conditions in Mexico, the tunnel will be robust for years to come thanks to its wall of reinforced steel and concrete segmental rings.



2 Descending
The entry points would operate as automated vertical lifts, which would safely descend from the surface into the tunnels below. From here the vehicles would merge into the relevant lane.



3 Gliding
Rather than driving independently within the tunnels, vehicles will be carried on a Loop system, an electric skate network that will ferry vehicles to their destinations at 200–240kph.



4 Future plans
There are plans for a 4.3km tunnel to be excavated in LA as a proof-of-process, but The Boring Company have also proposed a network of possible expansion routes across the city.

OVER WATER

How engineers harness the power of rivers and span huge natural barriers

Three Gorges Dam

- **Location:** Sandouping, China
- **Progress:** Completed, fully operational as of 2012

Meet the hydroelectric juggernaut that divides China's Yangtze River

The Three Gorges Dam is a monster. Its 2.3-kilometre length, 115-metre base width and maximum height of 185 metres spans the Yangtze River, making it the largest hydroelectric power station in the world.

By incorporating 27.2 million cubic metres of concrete and more than 460,000 metric tons of steel into its design, the dam supports an enormous reservoir that is capable of holding up to 42 billion tons of water.

Suffice to say, this dam can put out a lot of power. Estimated to generate 22,500 megawatts at maximum capacity, or around 11 times the energy output of the Hoover Dam in the US, the Three Gorges Dam has been pivotal to China shifting away from its reliance on fossil fuels and towards sources of renewable energy.

As well as generating energy the dam was designed to alleviate flooding of the Yangtze Basin

The bridge is built to withstand earthquakes, super typhoons and being struck by a cargo vessel

Hong Kong-Zhuhai-Macau Bridge

- **Location:** Lingdingyang Channel, China
- **Progress:** Complete, opened in 2018

The human-made thread of immense scale being built to connect three of China's most integral cities

The cities of Hong Kong and Zhuhai and the region of Macau have long been hindered in their interactions thanks to the Pearl River Estuary that separates them. But the three were tied together in 2018 thanks to a land bridge that spans

The Three Gorges Dam cost $37 billion (approximately £28 billion) to build

The bridge's construction could even be seen in satellite imagery, pictured here by Landsat 8 in 2015

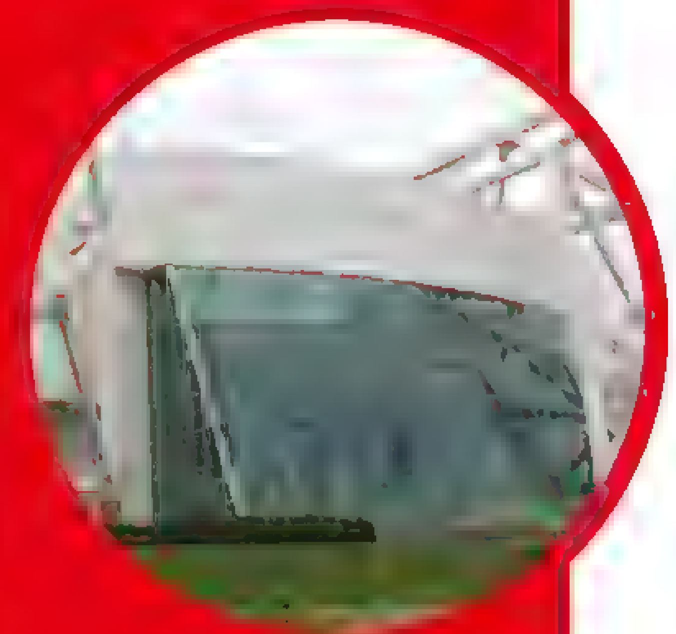
around 55 kilometres – 20 times longer than the famous Golden Gate Bridge.

A considerable portion of the bridge – almost 30 kilometres of it – straddles the estuary, and vehicles travel over the water in three lanes on both sides. Artificial islands then connect the bridge section to a 6.9-kilometre underwater tunnel, which is submerged to allow ships to traverse the water. Official projections believe the bridge will reduce travel times between the cities from four hours to just 30 minutes, and what a sight people will behold as they travel.

"The bridge will lower travel times from four hours to just 30 minutes"

ENGINEERING BLUNDERS

Kemper Arena, Missouri, US



In 1979, the Kemper Arena boasted a roof designed to hold water and release it slowly. The building wasn't equipped to deal with a rainstorm, however, and the weight of the pooled water soon proved too great and the roof collapsed.

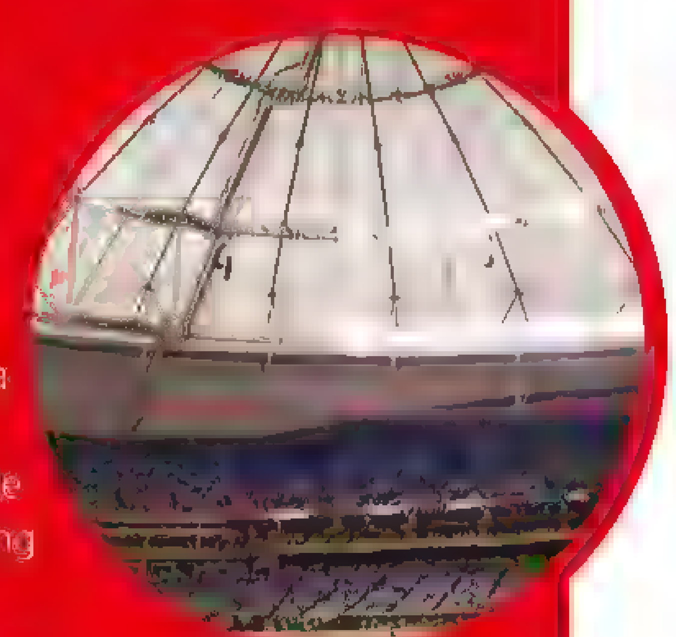
Walkie Talkie skyscraper, UK

London's well-known 'Walkie Talkie' building is eye-catching due to its concave shape. Unfortunately, this design choice concentrates sunlight onto the ground below, generating enough heat to melt the bumper of a Jaguar.

Tacoma Narrows Bridge, Washington, US

To save on cost, the engineers of the Tacoma Narrows Bridge used cheaper and insufficient materials during construction. This made the structure very unstable in high winds, and it soon collapsed after a particularly gusty day in 1940.

Tropicana Field stadium, Florida, US



Tropicana Field is home to the Tampa Bay Rays baseball team. Somewhat bizarrely, the stadium has a fixed roof, meaning that baseballs sometimes collide with the lighting, obstructing potential home runs and showering players or fans with shards of glass.

John Hancock Tower, Boston, US

John Hancock's namesake acquired a poor reputation shortly after construction was completed when its windows began falling out onto the streets below. It wasn't long before huge swaths of the window panes were empty and had to be filled with plywood.

Inside the city of caves

Welcome to SubTropolis: the underground business complex of Kansas City

SubTropolis was created via the mining of its 270-million-year-old limestone deposits

Famed for its unrivalled barbecue cuisine and jazz heritages, Kansas City is the largest city in the state of Missouri. But beneath the water fountains and theme parks, under the feet of the population of almost 500,000 people, is an excavated mine spanning an area equivalent to 140 football fields located almost 50 metres below the surface.

Known as SubTropolis, the underground system is in what was a limestone mine. After the mine closed it left a network of empty tunnels. This would later become a new business district. Development began in the 1960s.

With over 55 companies and more than 2,000 employees working there today, it is estimated that ten per cent of business real estate in Kansas is in the SubTropolis. You might expect this to feel cramped, but with five-metre-high ceilings the tunnels are actually surprisingly spacious.

GOING UNDERGROUND

The lower energy costs and cheap rent at SubTropolis made the move underground attractive to businesses, and the thick walls of carved limestone offer another advantage. The temperature is always between 18 and 21 degrees Celsius – perfect for hosting computer servers and storing food. From national archives to the treasured old films of Hollywood, SubTropolis is always predictably cool and safe from any natural disasters that might hit the city.

SubTropolis is a hub for e-commerce and acts as both a storage and distribution site for companies

5 FACTS ABOUT BUSINESSES AT SUBTROPOLIS

1 Knapheide
Ford Transit and Ford F-150s are taken to SubTropolis for fitting after being assembled at the manufacturing plant a few minutes away from the complex.

2 LightEdge Solutions
This is a cloud service company for businesses and a server storage facility that provides the power, security and connectivity they need to run.

3 Underground vaults and storage
Hundreds of thousands of Hollywood reels are stored at SubTropolis to keep them safe and cool in order to prevent them from deteriorating and being ruined.

4 Vanguard Packaging
This company prints supermarket displays and signs and moved into the complex to save money on heating and cooling bills and to provide a consistent temperature for their paper.

5 Paris Brothers
The Paris Brothers use the caves as an underground coffee storage facility while they wait to be transported to a roasting facility – the dark, cool environment is perfect for the beans.

The Seattle Space Needle

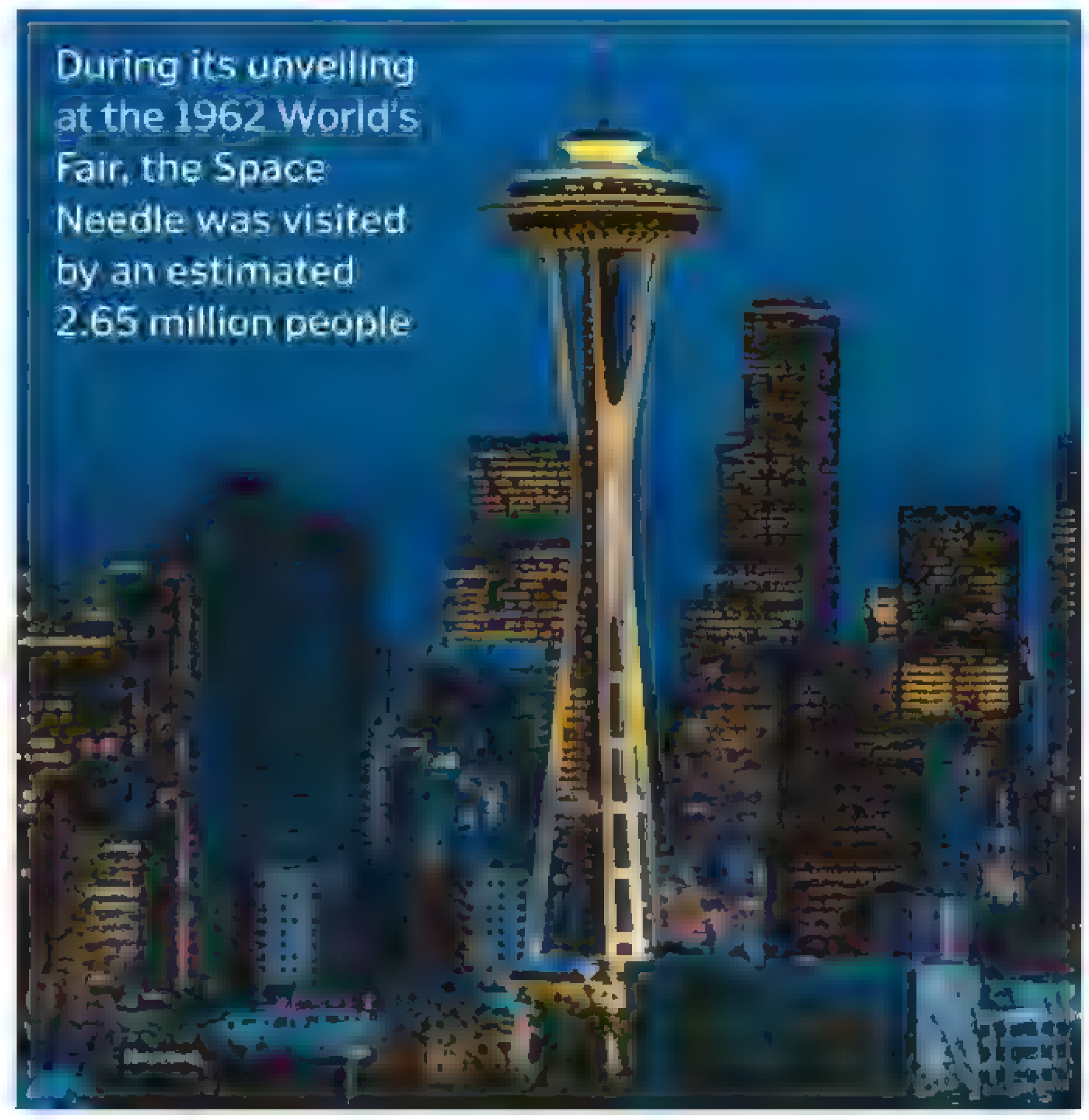
Created for the World's Fair theme 'The Age of Space' in 1962, the construction of the Space Needle was out of this world

Towering above the Seattle skyline is the iconic Space Needle. If you've never been to the US city then you might recognise it from the title sequence of the hit show *Frasier* or as a cutaway feature in the medical drama *Grey's Anatomy*. Before becoming a city showstopper, the Needle started out as a simple doodle on a restaurant napkin or placemat back in 1959.

While visiting Stuttgart in Germany, Edward Carlson, chief organiser of the 1962 World's Fair, sketched a design of a Seattle building to feature centre stage and host the Century 21 Exposition. Partnering with Seattle architect John Graham, the two transformed the initial skyscraper scribble into a towering reality.

After acquiring a plot of land of nearly 1,340 square metres, a hole over nine metres deep and 36.6 metres wide was excavated to provide the foundation of the building. To fill the massive hole, 467 vehicles poured 5,600 tons of concrete and 250 tons of reinforced steel into its foundation – at the time the largest ever concrete pour attempted on the West Coast. A set of steel tripod legs was then erected, which support the famous flying-saucer-style top-house. Construction was completed in a record-breaking 400 days, in time for the World's Fair.

Today, 56 years after it was built, the Space Needle is getting a transparent transformation. Hoisted nearly 159 metres above the street below, 48 glass panels – each weighing more than a ton – will replace the exterior structure of the observation deck. However, the observation deck isn't the only thing going glass; the floors of the famous rotating SkyCity restaurant have also been replaced so diners can have a bird's eye view of the city below.

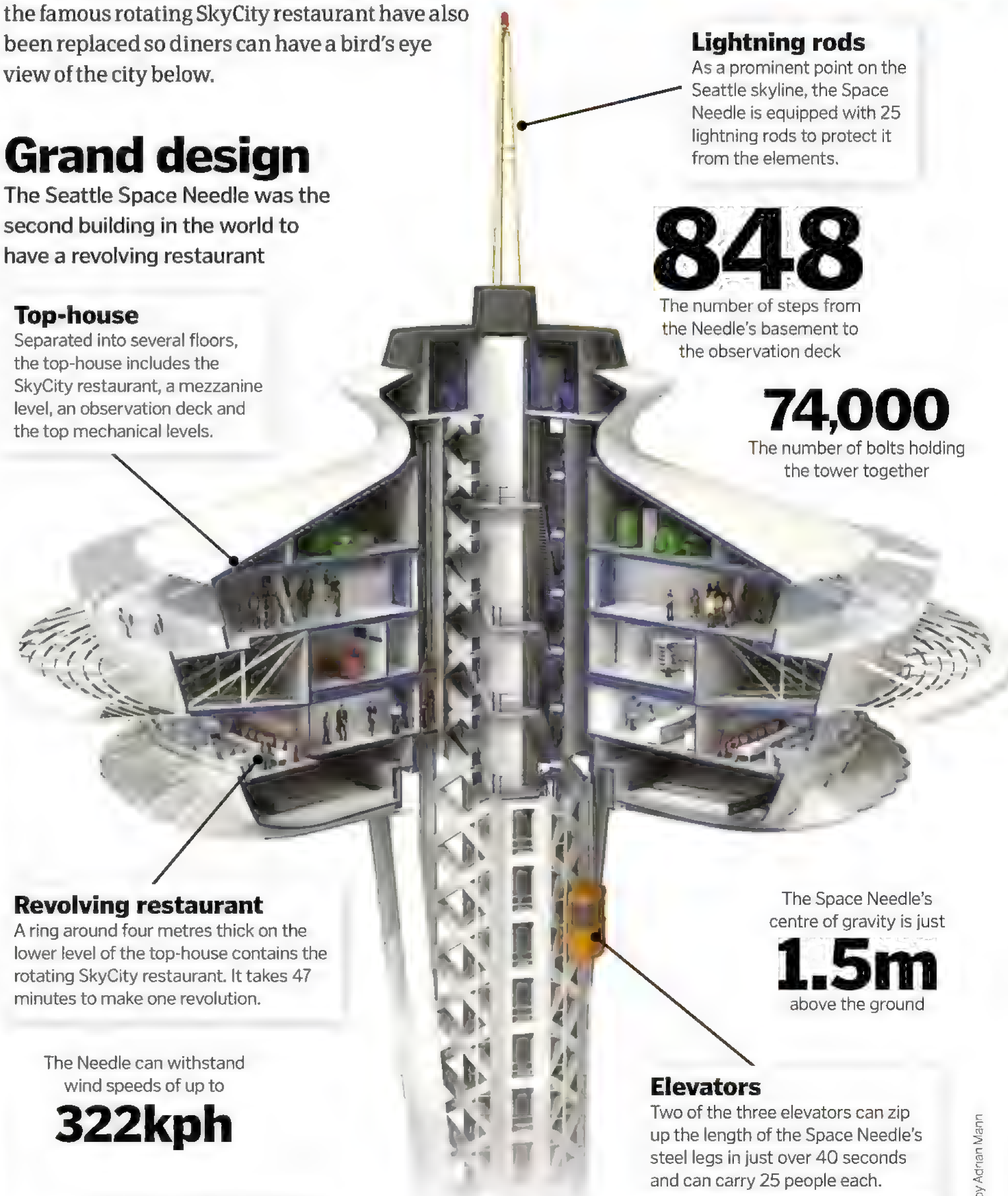


During its unveiling at the 1962 World's Fair, the Space Needle was visited by an estimated 2.65 million people

The revolving restaurant begins its ascent to form the Space Age top-house in August 1961

Grand design

The Seattle Space Needle was the second building in the world to have a revolving restaurant



Lightning rods

As a prominent point on the Seattle skyline, the Space Needle is equipped with 25 lightning rods to protect it from the elements.

848

The number of steps from the Needle's basement to the observation deck

Top-house

Separated into several floors, the top-house includes the SkyCity restaurant, a mezzanine level, an observation deck and the top mechanical levels.

74,000

The number of bolts holding the tower together

Revolving restaurant

A ring around four metres thick on the lower level of the top-house contains the rotating SkyCity restaurant. It takes 47 minutes to make one revolution.

The Space Needle's centre of gravity is just **1.5m** above the ground

The Needle can withstand wind speeds of up to **322kph**

Elevators

Two of the three elevators can zip up the length of the Space Needle's steel legs in just over 40 seconds and can carry 25 people each.

The Space Needle's elevators can travel at around **4m/s**

3,700 tons

The weight of the entire Space Needle structure

Extreme polar survival

Researchers employ advanced tech for both their science and survival when at the poles

Discover the gear that keeps people alive in the most unforgiving regions of Earth

Humans are, by design, warm-climate animals. Our skin lacks fur and we can't easily store a thick layer of insulating fat. Even so, we've now spread all around the globe, and an increasing number of people are finding reasons to venture into the most extreme latitudes found at our planet's poles. Due to climate change, previously solid ice sheets have thawed and opened the Northern Sea Route, making it accessible to traders, who've joined fishing vessels, oil rig workers and cruise ships in the colder waters.

On land, militaries with territory in the Arctic Circle have made permanent bases on the inhospitable terrain, and in the Antarctic region in the south researchers and adventurers continue to wrestle with nature, particularly during the brutal Antarctic winter. Yet we humans not only endure but even surmount nature's formidable challenges thanks to our ever-developing technology.

Some of the more amazing feats of engineering and design were on display during explorer Sir Ranulph Fiennes expedition to traverse Antarctica during winter. Although halted prematurely by mammoth crevasses, the expedition's team used the most advanced survival technology of the time to penetrate the frozen continent. Gloves and soles containing heating elements were woven into a power loom that ran throughout the suits, providing heat for the skiers' most vulnerable extremities. Their masks also used expired air to warm incoming fresh air, reducing the temperature gradient in their lungs. Beside them were two bespoke variants of the Caterpillar D6N tractor, equipped with a boiler and spare electrical heating element to allow the vehicle to operate at -70 degrees Celsius. This dragged their shelter and supplies.

Adventurers are not alone in utilising sophisticated technology, and whether it's soldiers equipped to march through the brutal winter months or fishermen shielding themselves against the elements as they await rescue, humans are more capable of surviving the extreme cold of the poles than they have ever been.

5 FACTS ABOUT THE TECHNOLOGY AND DANGERS OF POLAR SURVIVAL

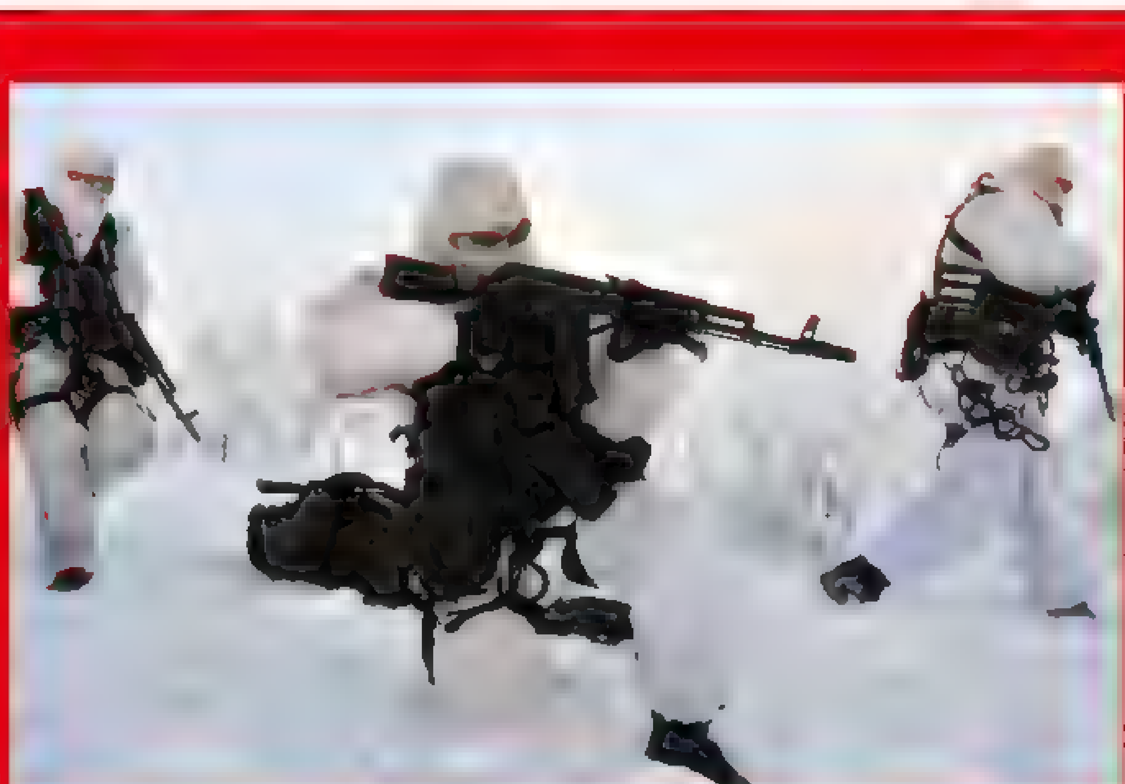
1 The human hypothermia recovery record
Doctors in Norway successfully resuscitated a patient with hypothermia so severe that their core body temperature had dropped to 13.7 degrees Celsius. Despite undergoing cardiac arrest the patient was saved.

2 Space technology on Earth
Cold survivalists have benefitted from NASA's space exploration, namely in the form of insulated materials. These include commonly used insulating 'space blankets' and temperature-resistant tapes.

3 Zero Celsius kills quickly
If you were to fall into a body of water at around 0 degrees Celsius unprotected your body would likely enter shock in less than two minutes and lose consciousness in less than 15 minutes.

4 Clothes with built-in warning sensors
Sintef's ColdWear Project has developed sensors that can be integrated into clothing. These will be capable of recording inputs such as humidity, wind, temperature and heat transport and can operate in extreme temperatures.

5 They treat hypothermia from the inside
Patients with body temperatures between 27 and 32 degrees Celsius can be treated with warm fluids directly into internal organs through tubing and IVs, which warm the body more effectively than external insulation.



Militaries with interests in the Arctic Circle are equipped with specialised gear for the extreme cold

Arctic military gear

Russia has multiple military bases on its northern frontier, which encroaches into the Arctic Circle. To ensure the country's troops are ready to defend this expansive border if the need arises, the military conducts drills at the North Pole to harden their soldiers against the cold and equips them with advanced clothing and equipment. They carry matryoshka boiling containers that can heat food despite outside temperatures of -50 degrees Celsius and wear buoyant, waterproof gear that can protect a soldier even if they remain in water for several minutes. Rather than this being a cumbersome piece of insulating gear, this uniform still allows a solider to function easily in combat and incorporates a bulletproof vest.

To the west, US soldiers have been training with synthetic materials in their clothing, sleeping bags and tents that are designed to expel water through temperature gradients. This means that if a soldier falls or has to swim in ice-cold water, they can dry themselves slowly simply through body heat.

Cold-water immersion suit

The meticulously engineered Arctic 25 can protect its wearer for over 24 hours in frigid conditions

Gone in 60 seconds
Acting fast is important in an emergency. Thanks to having just one sealable zip the suit can be donned in less than a minute.

Personal life-raft
The zip can be partially opened to reveal an additional cover that can be raised over the head and upper chest to shield against wind and rain.

Extremities
As well as insulated socks, boots and gloves, face masks that use expired air to warm inhaled air can be used in extremely cold conditions.

Two Caterpillar D6N tractors were specially modified to plough snow and generate power at incredibly low temperatures

Insulation
A micro-aluminised mesh, which roughly resembles bubble-wrap, fills the suit and keeps the wearer insulated against the cold water.

Buoyancy aid
Thanks to the water-tight and air-tight outer seal, the suit is three times as buoyant as a life jacket.

Layers trump thickness
Wearing thinner layers of appropriate materials will keep you better protected than a single thick layer.

Waterproof
The outer layer consists of sheets of hydrophobic polyethylene, which are melted together at their edges to seal the suit.

Survival gadgets
An included safety harness and buddy line will help crew members stick together, while a light and whistle will help guide rescuers.

Ready for the drop
The suit's material is strong enough to withstand the impact of falling 10m into water.

Sole protection
Vibram soles enable the suit to tread on both extremely cold and hot surfaces without freezing or melting.

Wrapping up warm

How to keep yourself dry, insulated and warm in the harshest conditions

Outer layer
The external layer is made of a robust synthetic material and acts as a barrier against water, ice and wind.

Optional mid layer
An additional insulating layer will help trap body heat. If a portable power supply is needed it can also be woven in here.

Base layer
An inner layer of merino wool will both insulate and carry away moisture from sweat, keeping you dry.

IN$IDE A MON£Y FACTORY

From workshop to wallets, how does the world's money reach our back pockets?

Words by **Scott Dutfield**

As online banking and contactless cards continue to grow as our preferred method of payment, physical money may one day be a thing of the past. However, with more than 3.6 billion Bank of England notes in circulation, making money is still a thriving business, one that's been around for thousands of years. Civilisation began this economic journey through bartering (the trading of items deemed of equal value) around 9000 BCE. It wasn't until around 600 BCE that Lydia, an ancient civilisation now part of Turkey, introduced the world's first coins as currency, made from a naturally occurring mixture of gold and silver called electrum.

As the concept of currency spread across the globe coins gave way to paper notes. Though sometimes referred to as 'paper' currency, traditional banknotes are not made from pulped wood but in fact cotton, or in the case of the US dollar, a blend of cotton and linen. Cotton bales are 'plucked' by heavy machinery before being filtered for imperfections and bleached. Fibres are then pressed to remove water and feed through rollers to form sheets. Watermarks and security features are placed on the sheets before final designs are printed and the notes are cut.

PAYING WITH PLASTIC

In recent years 'paper' money has been replaced by a thin, flexible plastic polymer material. These polymer notes are more resistant to dirt and moisture and have a stronger composition than their paper counterparts. Made from durable plastic compounds such as polyethylene terephthalate (PET) or biaxially oriented polypropylene (BOPP), the plastic notes start out as small pellets. These pellets are melted, and then stretched into an enormous bubble to cool that can stretch up to five storeys tall. Once the base of the bubble has cooled sufficiently it is rolled out into a sheet. This then passes through an infrared gauge to check the thickness. Once they have been quality checked, the sheets of plastic are rolled up, packaged and sent out for the final banknote designs to be added.

In the first half of 2018, about 223,000 counterfeit banknotes were discovered, so money makers have had to develop different ways to ensure the safety of their notes. Each note, depending on the country of origin, contains several security features that distinguish the real notes from the fakes. Polymer notes are much tougher to make forgeries of, and the addition of transparent windows, foils, holograms and ultraviolet treatments are used to verify their authenticity. Security measures are even applied to the artwork, with hidden designs, textures and raised print known as intaglio printing often used to foil would-be forgers.

Coin currency was first introduced in Lydia, modern-day Turkey, in around 600 BCE

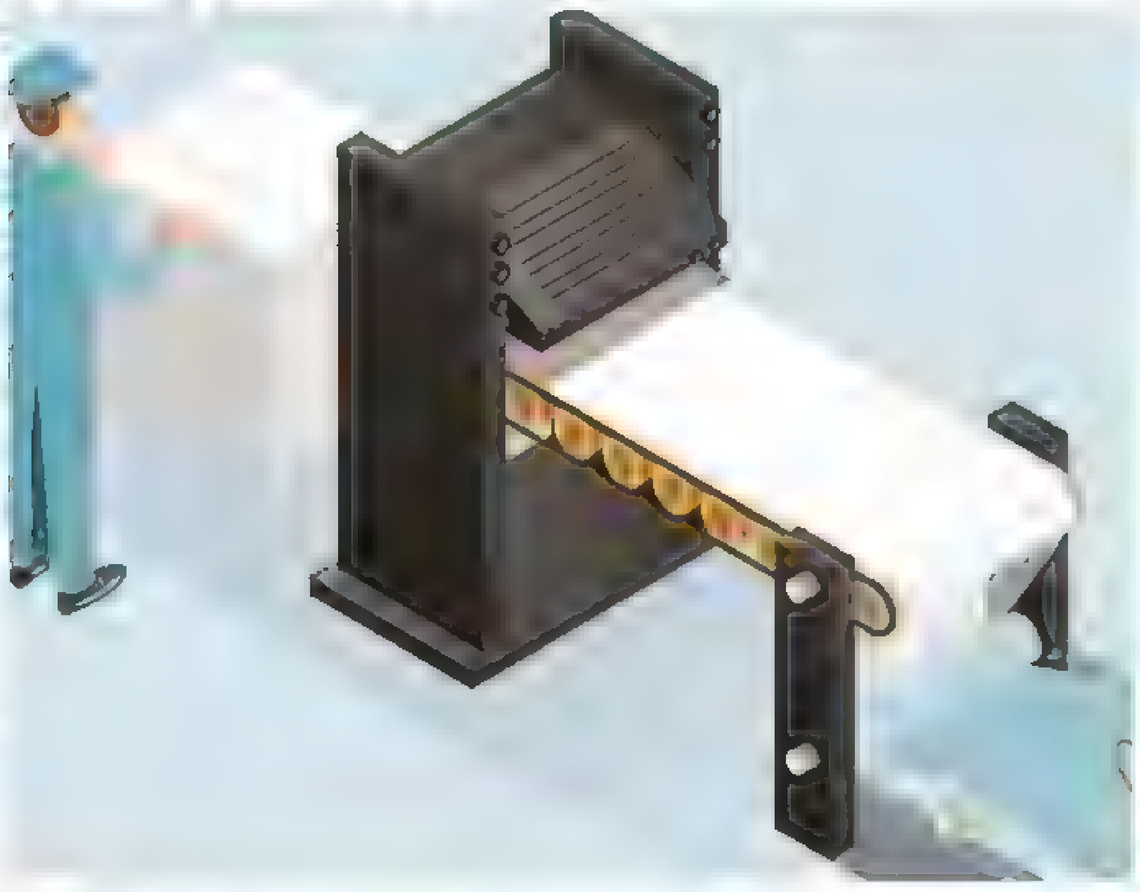
The polymer £10 note entered circulation in September 2017. It will be joined by a plastic £20 note in 2020

Show me the polymer

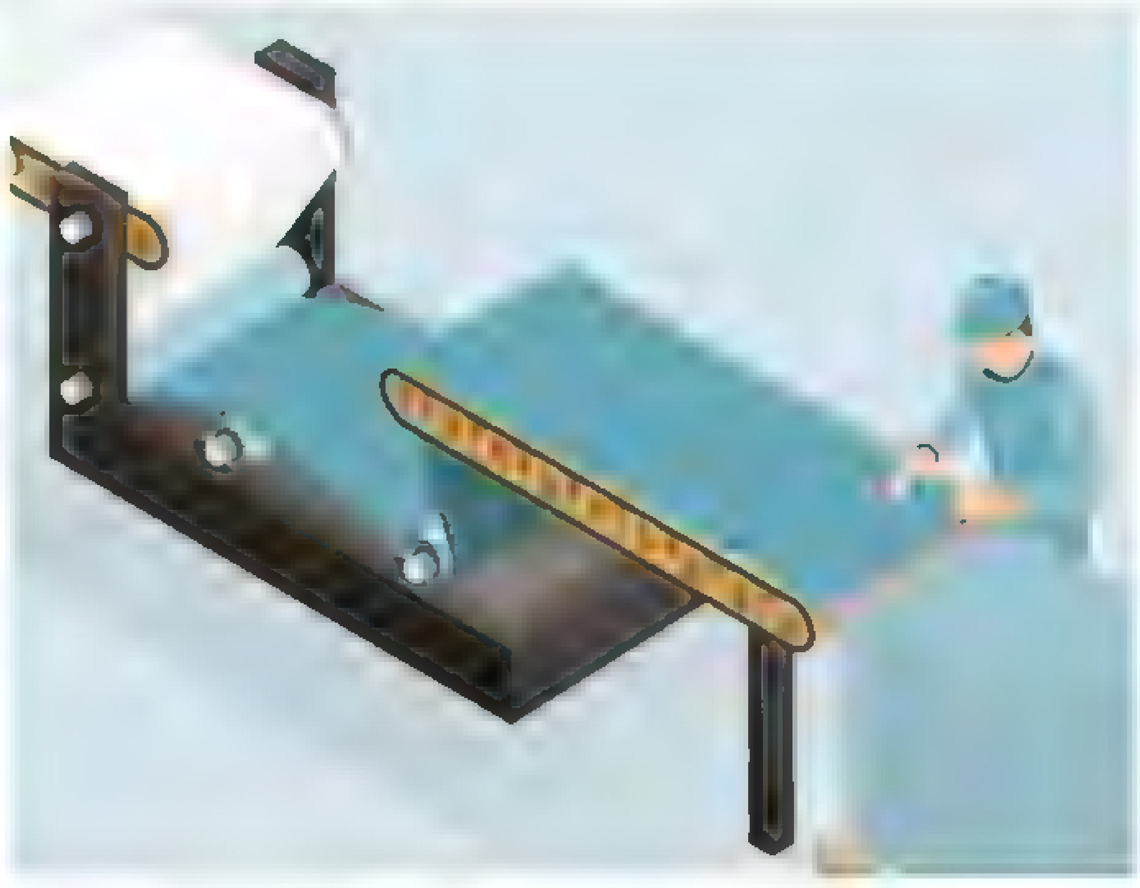
Ditching paper payment, these pioneering countries put polymer on the map

Putting a price on plastic

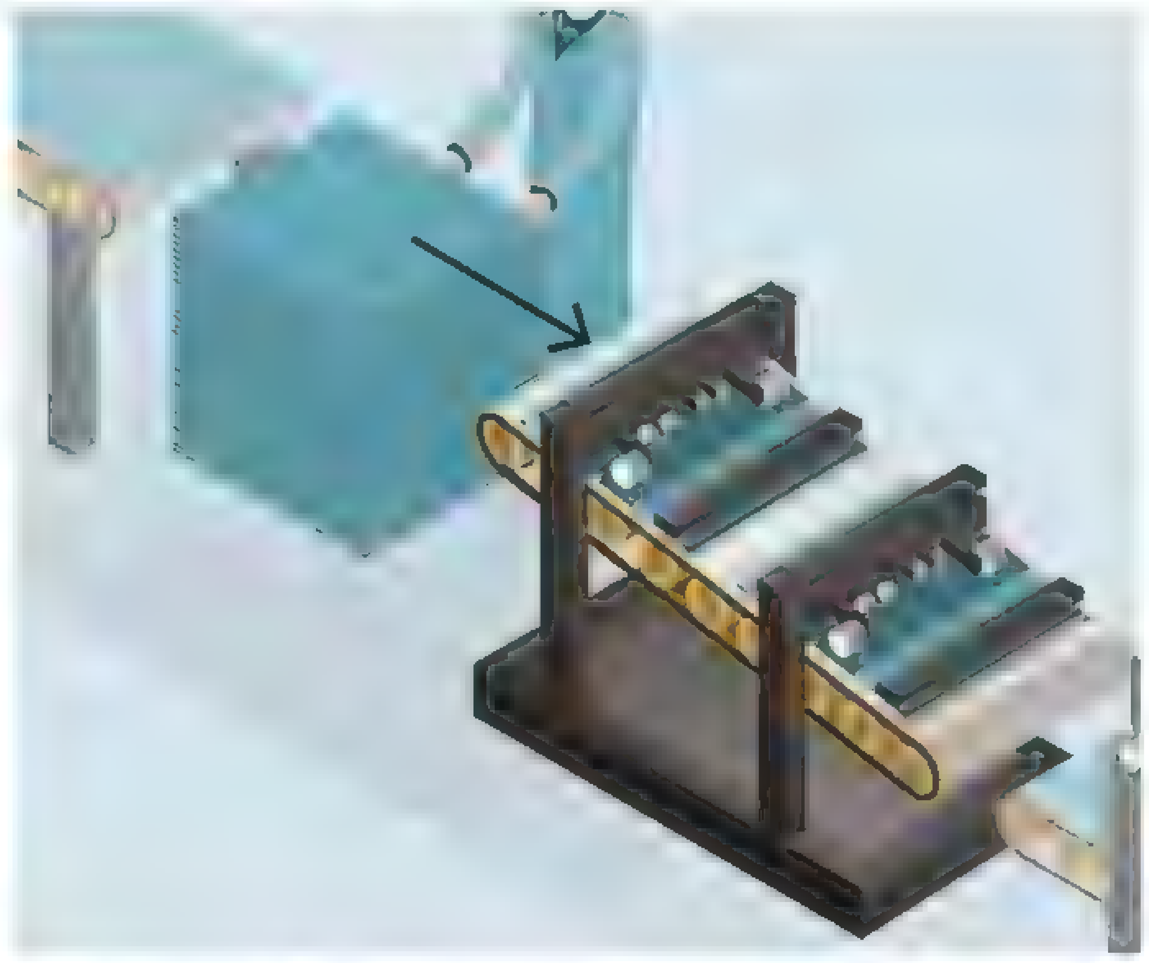
Step-by-step, how simple plastic is transformed into a valuable banknote



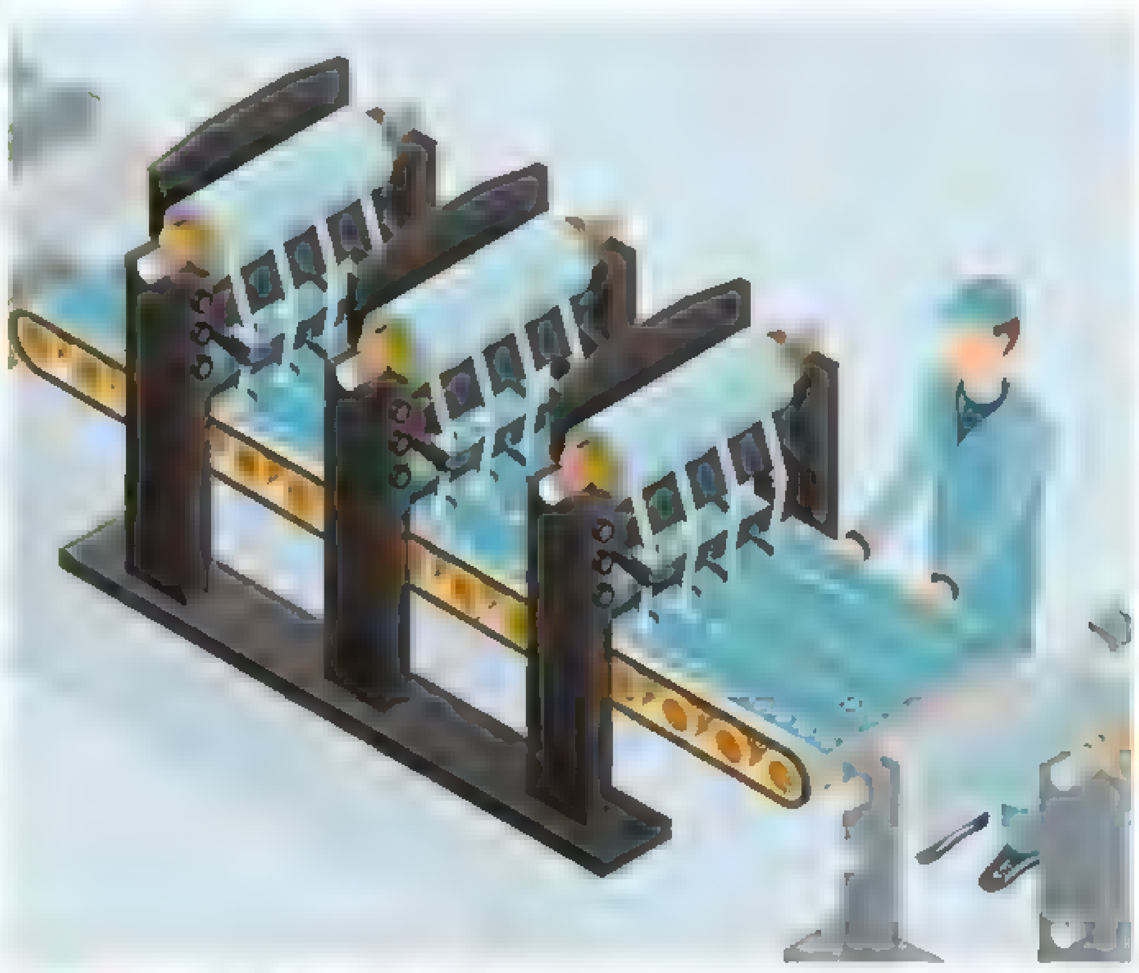
1 Blank sheets
Imported sheets of polymer substrate, housing the transparent window, are loaded into the printing process.



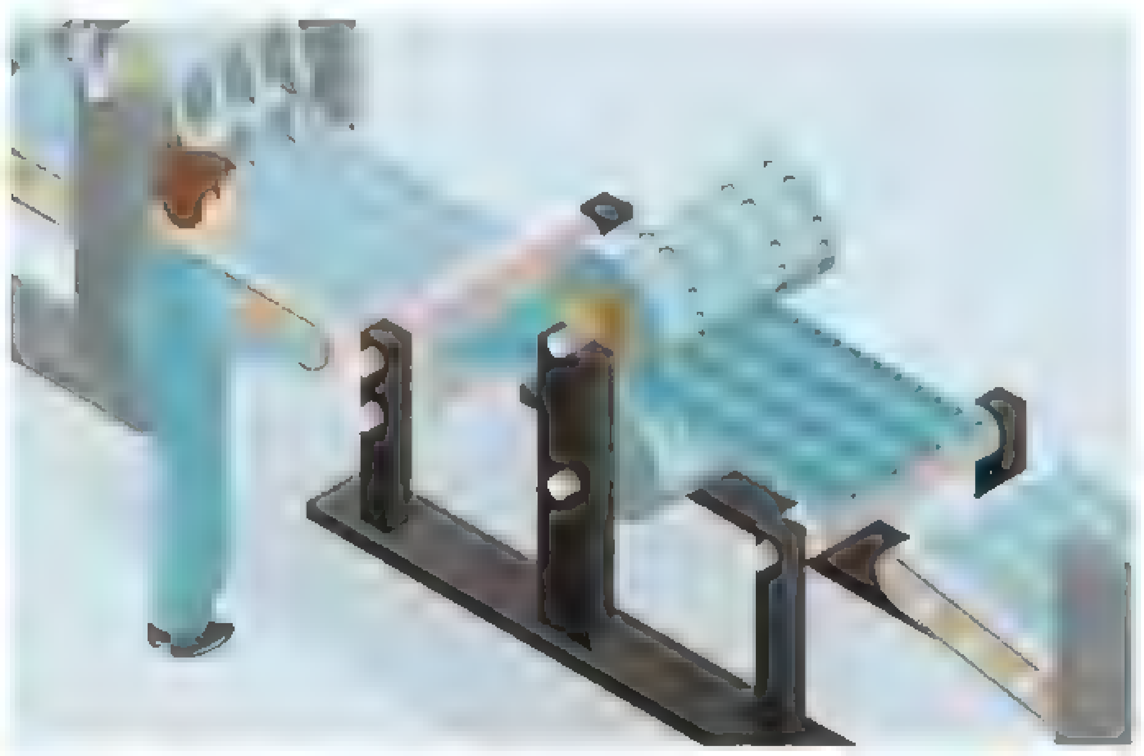
2 Base print
Computer-generated background designs are then printed onto both sides of the polymer sheets.



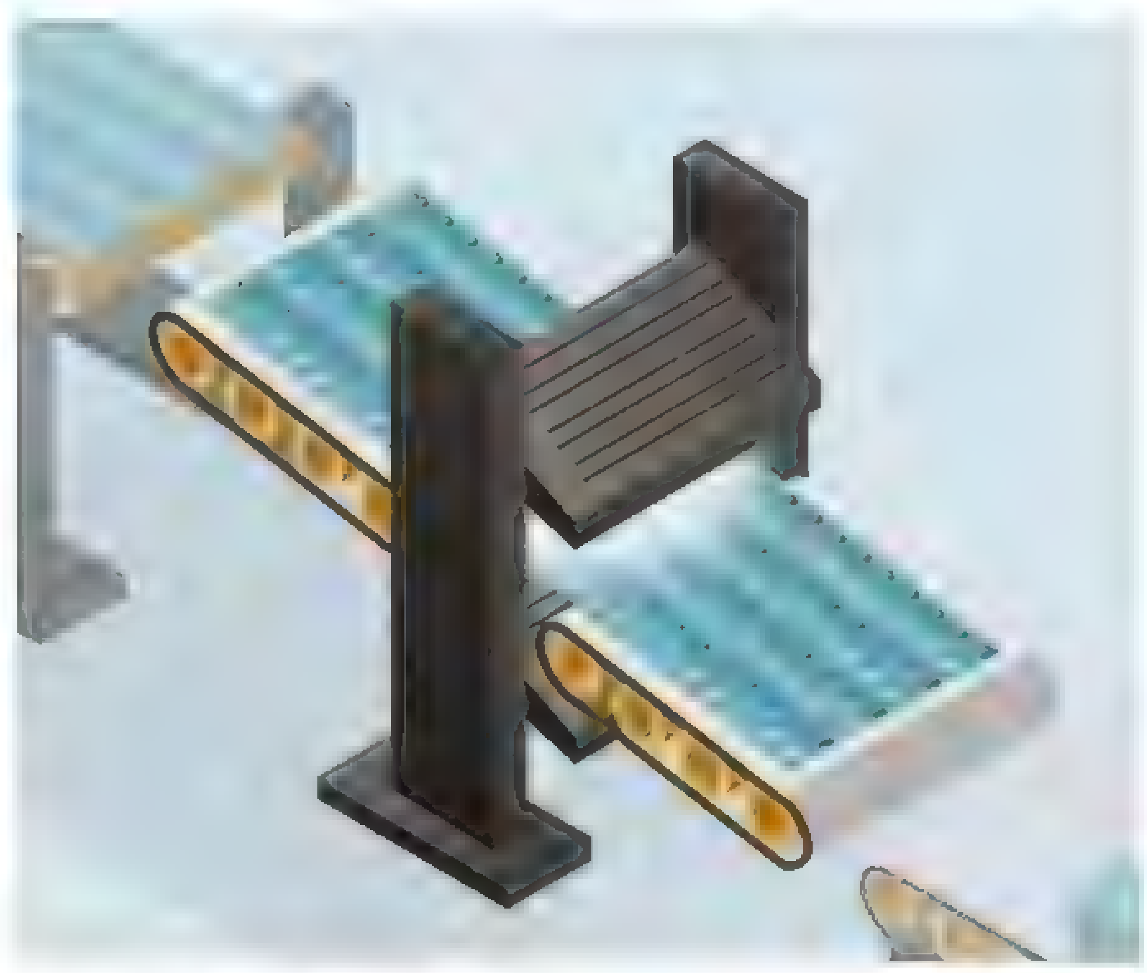
3 One at a time
Printed sheets are then fed individually into a foiling machine.



4 Applying foil
From a tape, strips of foil are applied to the uncut polymer sheets.



5 Security features
Portraits of county's iconic figureheads are then added to either side, such as Queen Elizabeth II. The printing for these portraits is typically intaglio or textured for security purposes, making them much harder to copy.



6 UV treatment
Sheets are then treated with ultraviolet light as a security measure.

Coin face designs are transferred onto stamp dies at the hand of a precise computer-controlled engraving machine

7 Making the grade
Quality control checks are carried out and the polymer sheets are counted.

8 Cutting to size
In order to separate the individual notes, stacks of sheets are put through a guillotine.

> *"See-through windows, foils, holograms and UV light are used"*

9 Final checks
Notes are then stacked, checked, tested and counted again.

10 Off to the banks
Finally, notes are packaged in bundles and stored in secure cages ready for transport.

Several security measures are taken to prevent fraudulent note production, including unique holograms

Creating coins

How the mint turns metal into coin currency

Raw materials
Rolled sheets of metal alloy of a precise thickness are fed into a blanking press.

Coin punching
Blank discs are punched out to their size and shape at a rate of up to 10,000 per minute.

Softening the metal
These future coins are then passed through an annealing furnace to soften the metal in preparation for stamping.

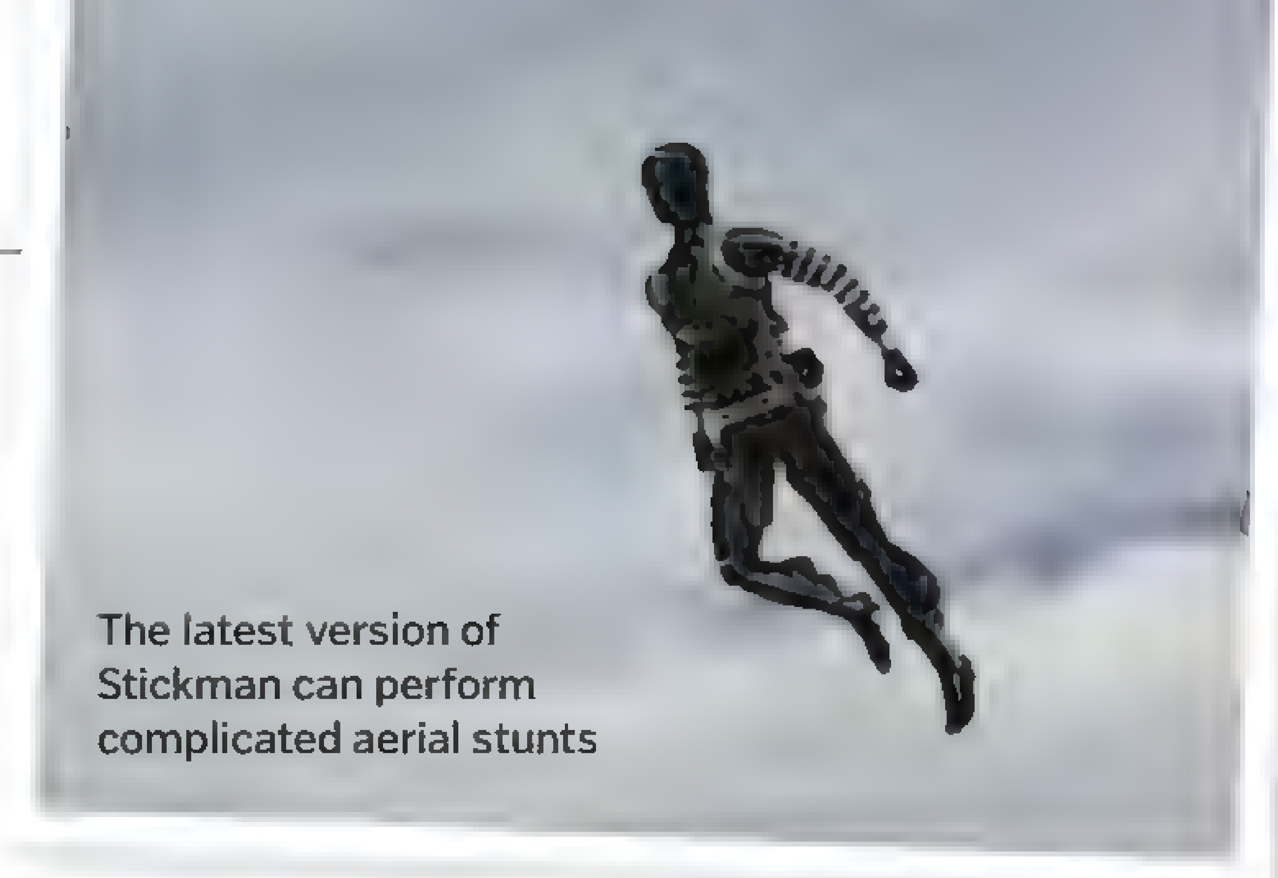
'Pickling' in acid
To remove any blemishes discs are added to a pickling bath, whereby ball bearings, sulphuric acid and the discs are mixed together to remove any imperfections.

Finished product
Freshly formed coins are checked and counted before being packaged and dispatched.

Stamping dies
Blanks are poured into the stamping press, where each of them is struck by a die/stamp that imprints the coins with their final design.

Disney's Stuntronics

Death-defying stunts are a breeze for these advanced acrobatic robots



The latest version of Stickman can perform complicated aerial stunts

The field of robotics has played a major role in many movies through the years. From animatronic sharks to mechanical monsters from far off worlds, robots have often been in the spotlight, particularly before CGI technology was widely adopted. Earlier this year, however, Disney released details of their new acro-bot, Stickman, showcasing robots' aptitude for stunt work as part of their 'Stuntronics' project.

Capable of performing mid-air flips and tumbles, Disney's Stickman somersaults through the air and sticks a perfect landing every time. It is just over two metres tall, similar in shape to an acrobat with their arms stretched out above their head and swings from a gravity-driven pendulum.

To begin the somersault, the Stickman is attached to the pendulum by a cable. As the pendulum swings, the robot will swing with it and at the perfect height will release from the cable, tuck, rotate, untuck and land. As it glides through the air, its motion is reminiscent of a gymnast somersaulting from the high bar.

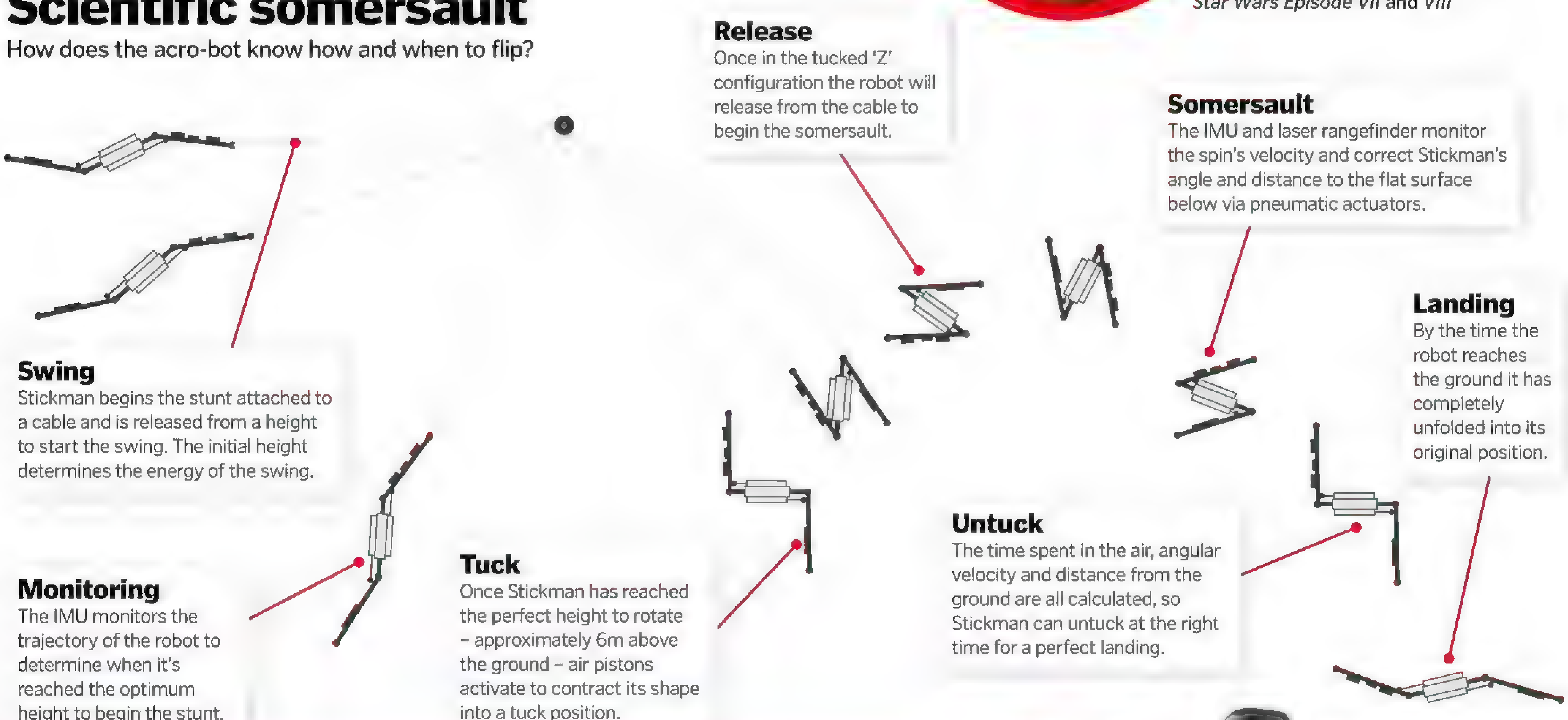
Stickman uses air tank stores to contract and extend its shape to achieve the somersault rotation. But it's the built-in Inertial Measurement Unit (IMU) that monitors and makes critical calculations of the robot's positions during movement to create the perfect flip. Together with laser rangefinders the robot can calculate its position and change its motion from flip to floor.

Since unveiling the relatively simple Stickman, Disney have released footage of their latest version, a 40-kilogram humanoid stunt figure that can make its own movement decisions in real time. This more realistic robot performs a range of flips and can soar through the sky like a superhero from the movies.

Disney Research is responsible for building the physical BB-8 used in *Star Wars Episode VII* and *VIII*

Scientific somersault

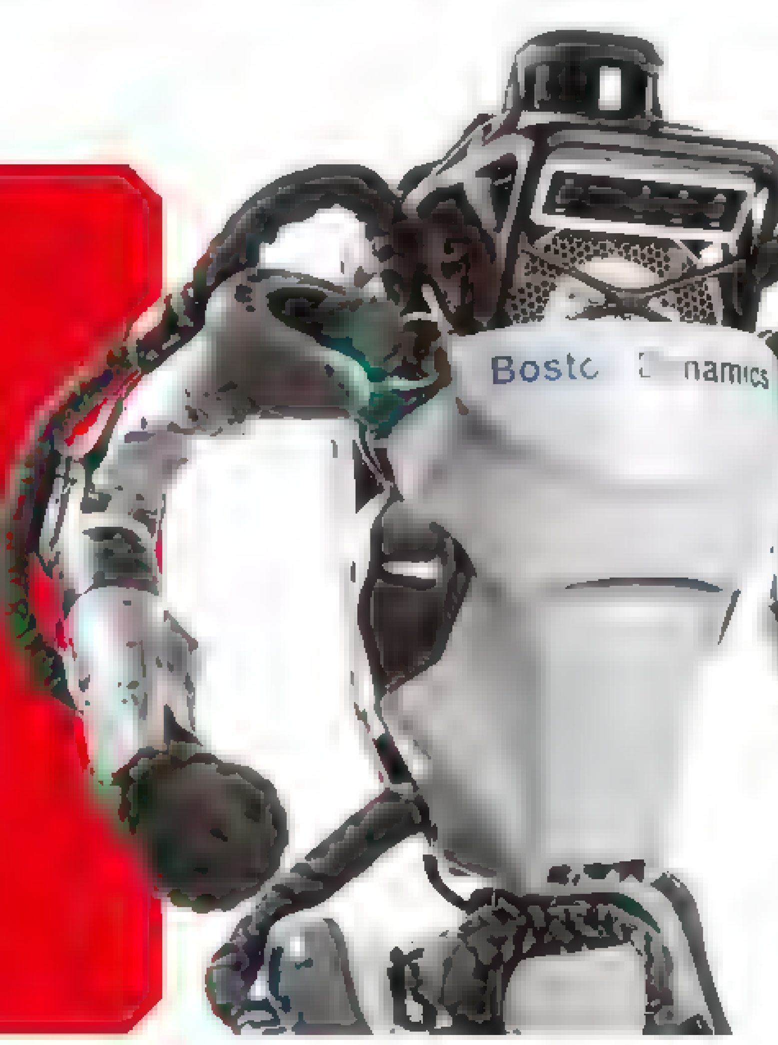
How does the acro-bot know how and when to flip?



Dynamic duo

The creation by Disney's research division is not the only robot capable of somersaulting on its own. One of the leading developers in robotics is Boston Dynamics, and they have created a robot that can perform a perfect backflip.

Atlas is a humanoid robot that can coordinate its limbs and torso to replicate human motion. It uses lidar and stereo camera vision as its eyes to see the world. Lidar is a detection system to map out Atlas' surroundings, much like radar but using light. This 'light radar' measures the time taken for a small beam of light to hit the ground or surroundings and return to Atlas. This time can then be converted into distance, creating the perfect picture of the world around it.



Atlas was created by Boston Dynamics and is designed for search and rescue missions

Peculiar power sources

With an increasing awareness of our finite fuel resources, researchers are investigating how we can extract energy from some of the most unlikely sources

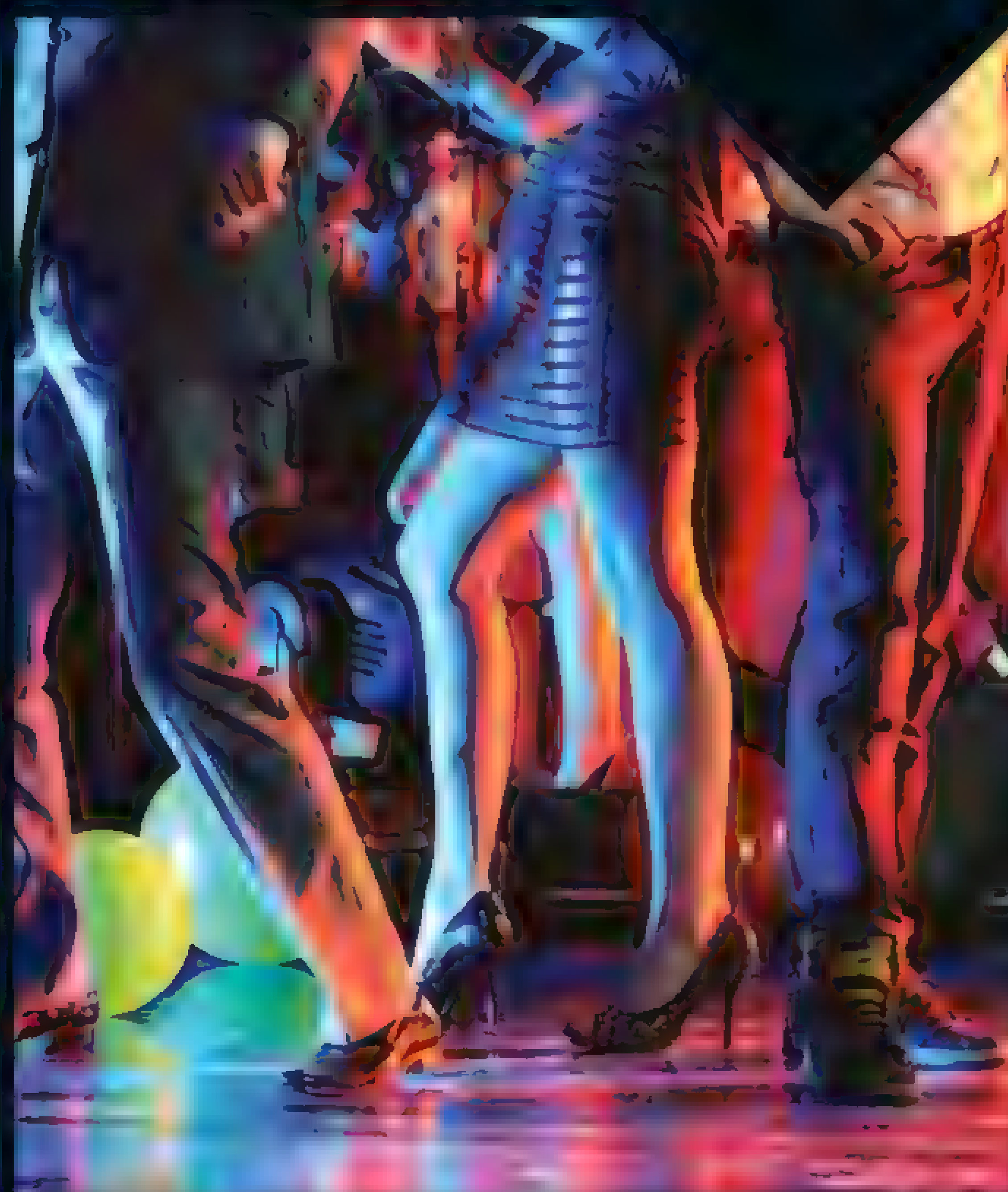
In 1986, a limnic eruption at Lake Nyos, Cameroon, released around 80mn m^3 of CO_2, suffocating over 1,700 people and thousands of animals

Exploding lakes

So-called 'exploding lakes' contain massive reservoirs of methane and CO_2. Under normal conditions the water's density keeps the gasses trapped below, but when a lake's temperature (and therefore density) changes the gasses can violently erupt with a cloud of deadly, suffocating gasses called a limnic eruption. However, harnessing these dangerous substances could both save lives and provide power. The KivuWatt project in Rwanda extracts methane from Lake Kivu and sends the gas via a pipeline to a power plant to generate electricity.

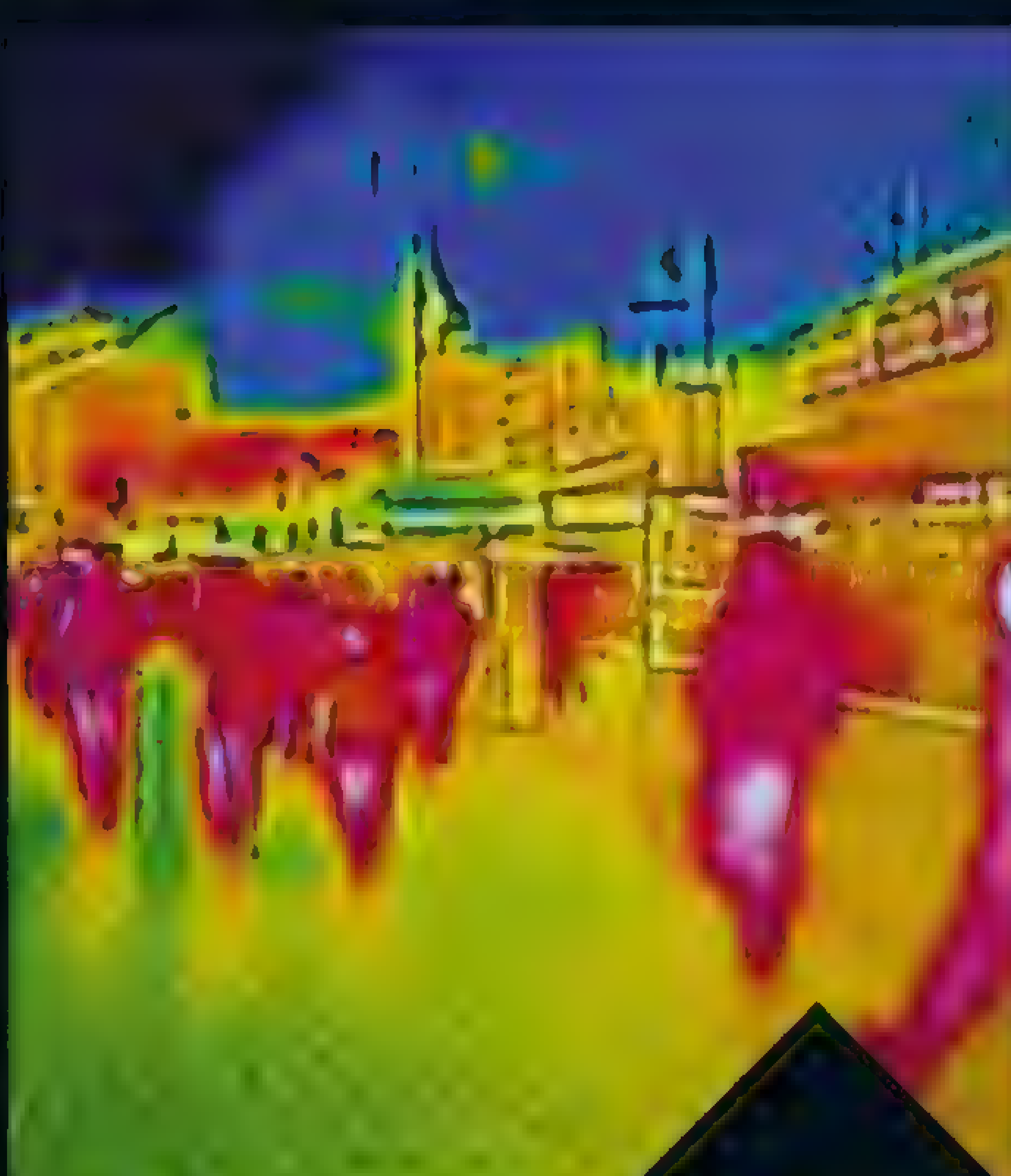
Parties

Imagine hitting the dance floor to your favourite songs and knowing that while you were dancing you were helping to power homes? Club Watt in The Netherlands is doing just that by using floor vibrations to power the lights. The company Energy Floors have created tiles that contain an electromechanical system, transforming small vertical movements – when they're stepped on – into a rotating movement, which drives a generator positioned below to produce electricity.



Coffee grounds

Globally, over 2 billion cups of coffee are drunk each day. But rather than binning the leftover grounds, what if we could use them as fuel? Bio-bean are a UK company that have turned this idea into a business, collecting waste coffee grounds from businesses and turning them into various biofuels and biochemicals. By removing moisture from the grounds and compressing them into pellets, the company can create coffee 'logs' that customers can use instead of traditional wood on fires.



Body heat

Buildings can be heated efficiently by harnessing the body heat of crowds – particularly those in shopping centres and train stations. In Stockholm Central Station, Sweden, the body heat of around 250,000 passengers a day is used to heat a nearby office block. In the station's ventilation system, heat exchangers transfer the thermal energy from the air to water in the pipes, which is then pumped to the neighbouring office's heating system.

Poo power

It might sound gross, but this is one power supply that will never run out! When bacteria feed on faeces under anaerobic conditions they produce methane and carbon dioxide gas, which can be stored and used as fuel. Some companies even process human waste into a hygienic solid fuel that can be used as a replacement for coal.

Jellyfish

Current technology limits the amount of energy we can collect and store from solar power, but scientists are now investigating how we can use 'biosolar' sources. Golden jellyfish host large amounts of algae-like organisms – which photosynthesise very efficiently – within their tissues. By harvesting the photosynthesising 'reaction centres' of these organisms scientists could create much more efficient biosolar panels.

The future of shopping

Amazon Go's smart store means you'll never have to queue again

While Amazon has revolutionised the way we shop with its online service, the retail giant clearly thinks there is still a future for shopping outside of cyberspace. In January 2018, the first bricks and mortar Amazon Go convenience store opened to the public in Seattle, US. However, unlike any other shop, this one lets you pick up the items that you want and pay for them without having to wait in clogged queues for a cashier.

No, we're not simply talking about self-checkout tills. This futuristic store uses a high-tech surveillance system that Amazon calls 'just walk out technology'. Using computer vision, hundreds of cameras monitor the store from every angle, allowing machines to 'see' what is in front of them and determine what objects are. This allows the store to not only follow the shopper but identify everything they pick up. This is then added to a virtual cart and automatically billed to their account when they leave the store.

However, this system is sophisticated enough to also track when you pick up an item (for instance, to consult its ingredients list) then put it back on the shelf. This is because the futuristic store is also fitted with numerous other detecting devices, likely including weight sensors in the shelves.

All of the information the store's many sensors collect is analysed in the same way Amazon Echo recognises voices, with machine learning working over the cloud – harnessing the power of the tech firm's massive data centres – to calculate your purchases. However, the process is not entirely automated. Behind the scenes, there are still some human employees helping to train the algorithms and double-check they've identified the correct products. People are also employed to prepare fresh food items, restock the shelves and to check shoppers' IDs for buying alcohol.

Customers scanning their phones to enter Amazon Go as it opened to the public on 22 January 2018

Banks of cameras and sensors in the ceiling track shoppers' purchases

DID YOU KNOW? As of January 2019, Amazon Go has stores in Chicago, Seattle and San Francisco in the United States

Grab-and-go shopping

Amazon's super-smart stores are the closest thing to legal shoplifting

"Hundreds of cameras monitor the store from every angle"

1 Gaining entry
To begin shopping, scan the Amazon Go app on your phone at one of the entrance's turnstiles. A sensor will read your app's unique QR code.

2 Smart surveillance
Hundreds of cameras – including regular RGB lenses, as well as depth-sensing cameras – monitor customers' movements using computer vision.

3 No-pressure shopping
Pressure plates on shelves help the store's computer system track when you have picked up an item or put it back.

4 Next-gen barcodes
Some products, in particular fresh sandwiches and salads, are labelled with dotted codes that help the cameras identify them.

5 No checkout queues
Once you've finished shopping you simply walk out the store – you don't even have to scan the app again before you leave.

6 Pay on the Go
Once you leave the shop your bank account will be charged and an electronic receipt will be sent to your Amazon Go app.

7 Wide selection
In addition to selling popular brands, the store stocks some exclusive own-brand items, including Amazon Meal Kits.

8 Not entirely automated
While there are no cashiers, people are still employed to stack the shelves and prepare fresh food.

9 Shop with friends
A shopper can bring up to two guests with them by scanning to let them in first, but the shopper will be charged if these guests take anything.

10 Crowd control
The roughly 167m² Seattle store can accommodate around 90 shoppers at one time. This cap is due to fire safety rather than limitations of the store's tracking technologies.

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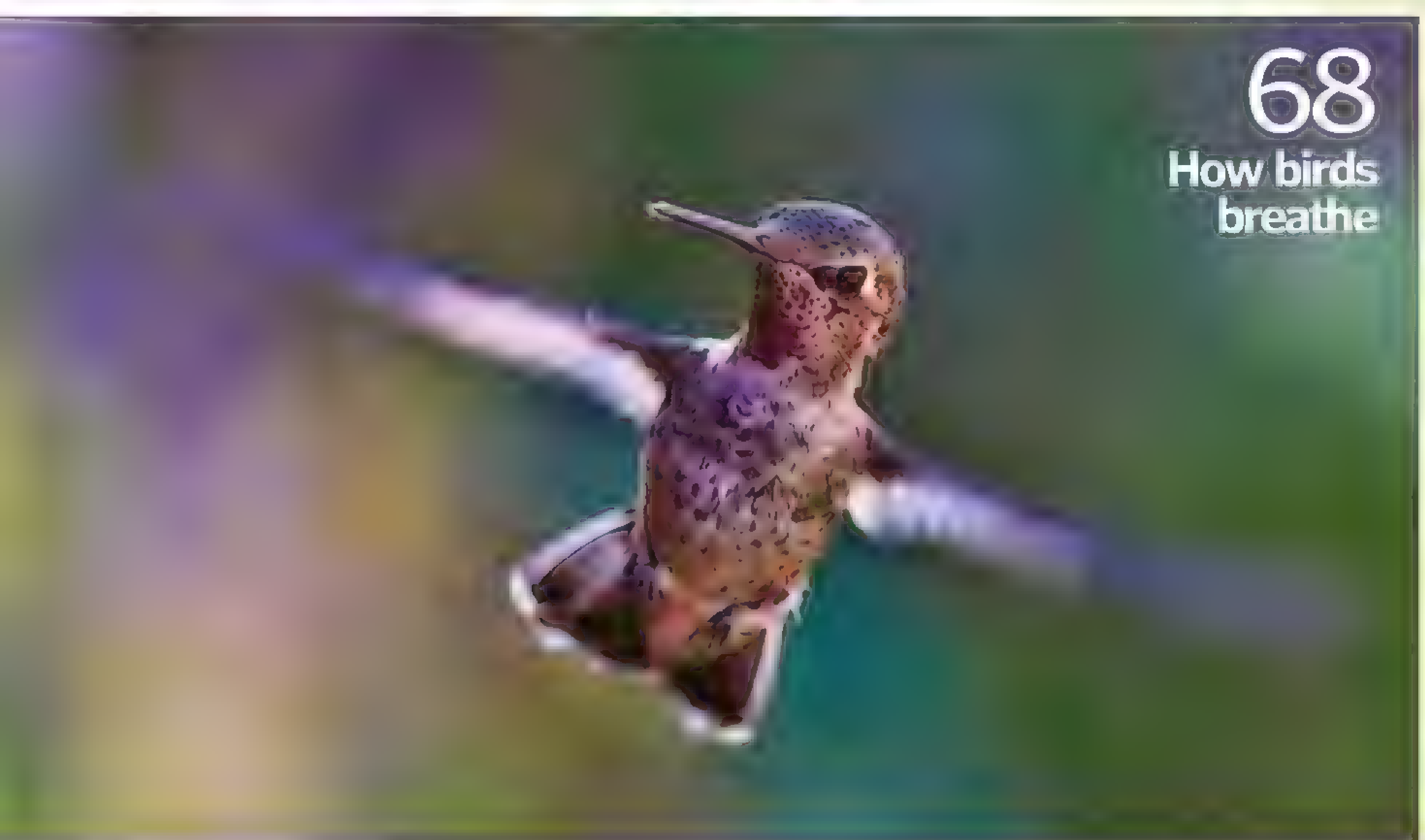

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How birds
breathe

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creatures

EARTH IN A YEAR

Compress Earth's unimaginably vast history into 12 months and humans saunter in just in time for the New Year's party

JAN FEB MAR

1

4.54 BILLION YEARS AGO

Earth is estimated to be about a third of the age of the universe. The Sun and planets formed from the cloud of dust and gas that comprised the young Solar System when gravity caused material to clump together.

4

4.51 BILLION YEARS AGO

The Moon was formed not long after the Earth. According to the most widely accepted theory it was created when Earth collided with another planet in a 'giant impact', sending debris into orbit.

24

OCT

OCTOBER 1

1.2 BILLION YEARS AGO

At some point around a billion years ago a few organisms stopped reproducing by simply splitting in half and started to reproduce sexually with other members of their species.

NOV DEC

12

240 MILLION YEARS AGO

Dinosaurs evolved from other reptiles and began to roam the Earth. When the planet's history is compressed into a year, they survived for just two weeks.

30

400 MILLION YEARS AGO

Insects appeared at least 400 million years ago – possibly as early as 480 million years ago. Early species were restricted to crawling over land and plants, but one line went on to evolve wings and take to the air.

23

470 MILLION YEARS AGO

31

2560 BCE

1066

1492

44 BCE

1760

1666

Some scientists believe that high-speed crashes in space created celestial bodies like the Moon

APR MAY JUN

22

2.4 BILLION YEARS AGO

Certain bacteria began to use sunlight to convert carbon dioxide and water into sugar – the same process used by green plants. Oxygen was released as a waste product, creating an oxygen-rich atmosphere that would later support animals with lungs

3.5 BILLION YEARS AGO

Around 3.5 billion years ago, after asteroids had stopped raining down on the planet, Earth became less barren as life evolved. These organisms, each made up of a single cell, are the ancient ancestors of every species alive today

Insects were flying around long before dinosaurs came onto the scene

JUL AUG SEP

175 MILLION YEARS AGO

The supercontinent Pangaea began to split apart. Carried in different directions by tectonic activity, the pieces would eventually become the modern continents.

200 MILLION YEARS AGO

Early mammals evolved – these were small, nocturnal shrew-like animals that hunted insects. Mammals stayed in the background until the extinction of the dinosaurs, after which they rapidly diversified and grew

17

15

130 MILLION YEARS AGO

[illegible]

AROUND 315,000 YEARS AGO

[illegible]

22

31

26

68 MILLION YEARS AGO

[illegible]

[illegible]

MISSION REFORESTATION

Restoring Earth's depleted forests is no mean feat, but blending science and nature can bring woodlands back from the brink

Words by Ella Carter

DID YOU KNOW? *Across the world there are 300 million people who live in forests, including 60 million indigenous people*

It's true what they say: forests are the lungs of our planet. Trees purify our air, taking in carbon dioxide and expelling oxygen into the atmosphere for us to breathe. Forests help to regulate our climate, wood from the trees provides us with essential fuel and building materials, and they form vast habitats for plants and animals. Tree roots stabilise the earth, maintaining nutrients in the soil that nourish the crops that feed us and support the livelihoods of millions. Forests are essential to human survival on a primal level.

While some 30 per cent of the land area of our planet is currently covered by forested areas, it is disappearing at an alarming rate. According to data published by the Food and Agriculture Organization, between 1990 and 2015 deforestation demolished some 129 million hectares of the world's forests. The worst-hit areas were sub-Saharan Africa and Latin America.

Where deforestation is the loss of trees, reforestation is the exact opposite. Innovative strategies and dedicated projects are put in place to reintroduce trees and forests to areas that have been cleared. The consequences of deforestation are loss of biodiversity, loss of habitat and soil erosion, which removes nutrients from the ground, making it unsuitable for agriculture. This also leads to flooding and the silting up of rivers. In addition, the perpetual loss of trees that take in carbon dioxide, coupled with the burning of fossil fuels, ultimately contributes to overall climate change. Reforestation is essential in attempting to reverse these detrimental effects.

> *"Forests are essential to human survival on a primal level"*

In its extremes, deforestation can lead to desertification, which is where previously wooded lands become barren, dry and infertile. These deserted areas have a huge impact on not only the environment but also on the people that depend on their ecosystem. For example, in the Sahel Zone in central Africa the Sahara Desert is an ever-expanding threat to around 309 million people who live there.

It's in these areas, on the front line of global climate change, where reforestation projects are most important. There are many different initiatives and ways to bring trees back into ecosystems, and one is the Great Green Wall.

The Great Green Wall project began in 2007 and was first proposed as a huge 15-kilometre-wide band of planted trees that would stretch 8,000 kilometres from the east to west across the Sahel, spanning 11 countries. In reality, it is a patchwork of plantations across the region and is currently around 15 per cent complete. Senegal is the furthest ahead with this initiative, having planted 11.4 million trees in a bid to reverse desertification.

The replanted drought-resistant acacia trees hold water in the soil, which means that wells can refill, providing communities with more water. The leaves provide shade, which means that the need for watering is reduced, and they also provide compost. More crops mean more work is available, leading to economic growth, enabling communities to thrive rather than just survive – all thanks to the trees. Although it's still many years from completion, it's hoped that the Great Green Wall will have a monumental impact upon the region.

5 FACTS ABOUT THE CAUSES OF DEFORESTATION

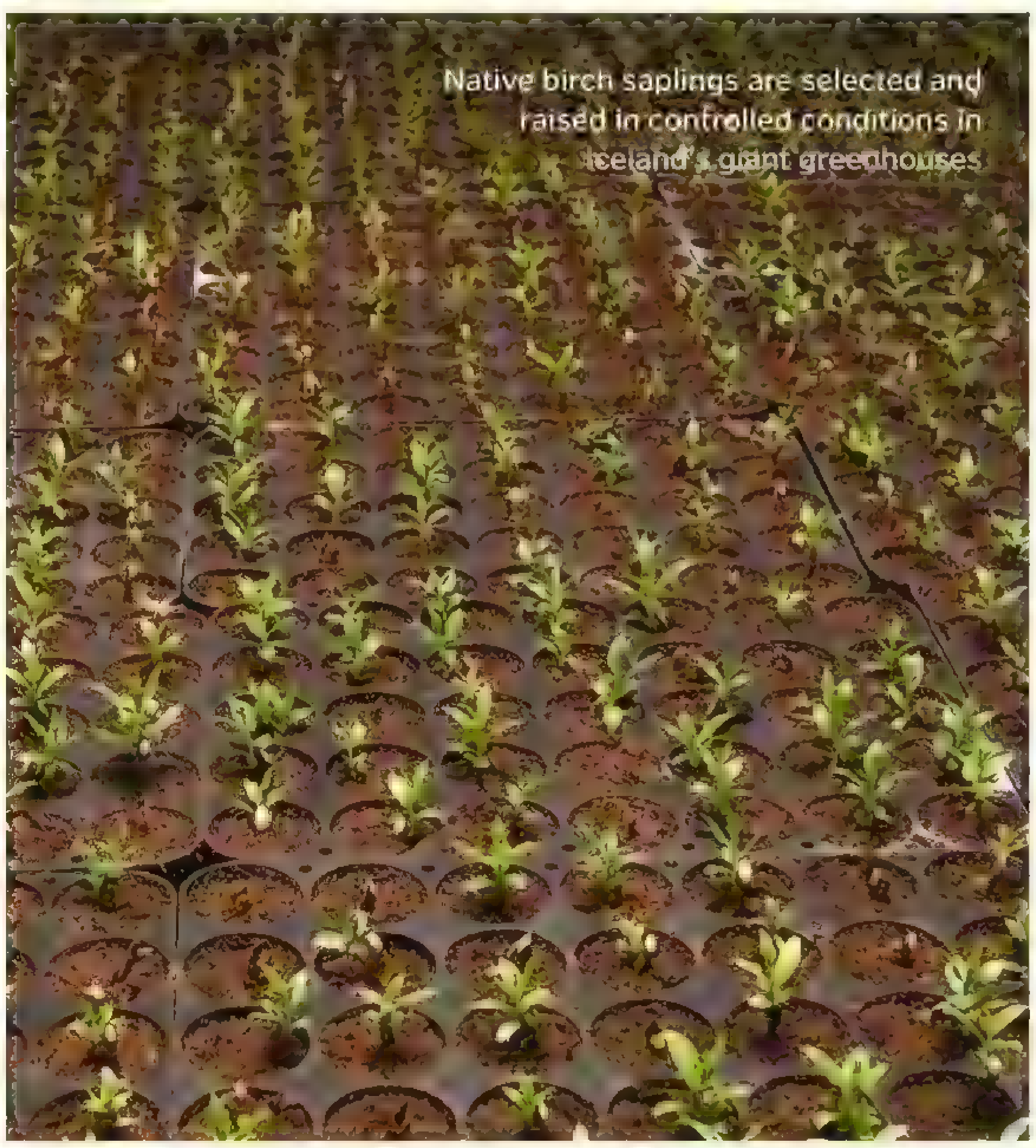
1 Agriculture
Forested areas are being cleared to make way for crops, such as palm oil, and to create space for livestock as global demand increases.

2 Forest fires
Although they can occur naturally, forest fires at the wrong place or time destroy forests. 'Controlled burns' are intentional fires that are often used as a swift method to clear ground.

3 Mining
Rainforest areas contain high levels of valuable mineral deposits such as gold. Mining these materials is highly destructive as it requires the clearance of nearby trees.

4 Infrastructure
To conduct mining or logging operations, large forest areas are cleared to make way for roads.

5 Logging
Legal and illegal operations hugely impact the forests as timber is cut down and exported.



Native birch saplings are selected and raised in controlled conditions in Iceland's giant greenhouses

Agroforestry is another method of reforestation where trees are planted among other plants and crops

Just like the acacia trees that are perfectly adapted to their surroundings, the species that are planted in order to bring the forests back need to have enough sticking power to survive. Iceland may seem an unlikely victim of deforestation and desertification compared to the hot, dusty Sahel or the tropical Amazon, but it has suffered a huge loss of natural biomass thanks to thousands of years of overgrazing and logging, much of which the region's early settlers were responsible for.

> *"The strongest and sturdiest thrive, and the result is a natural, organic forest"*

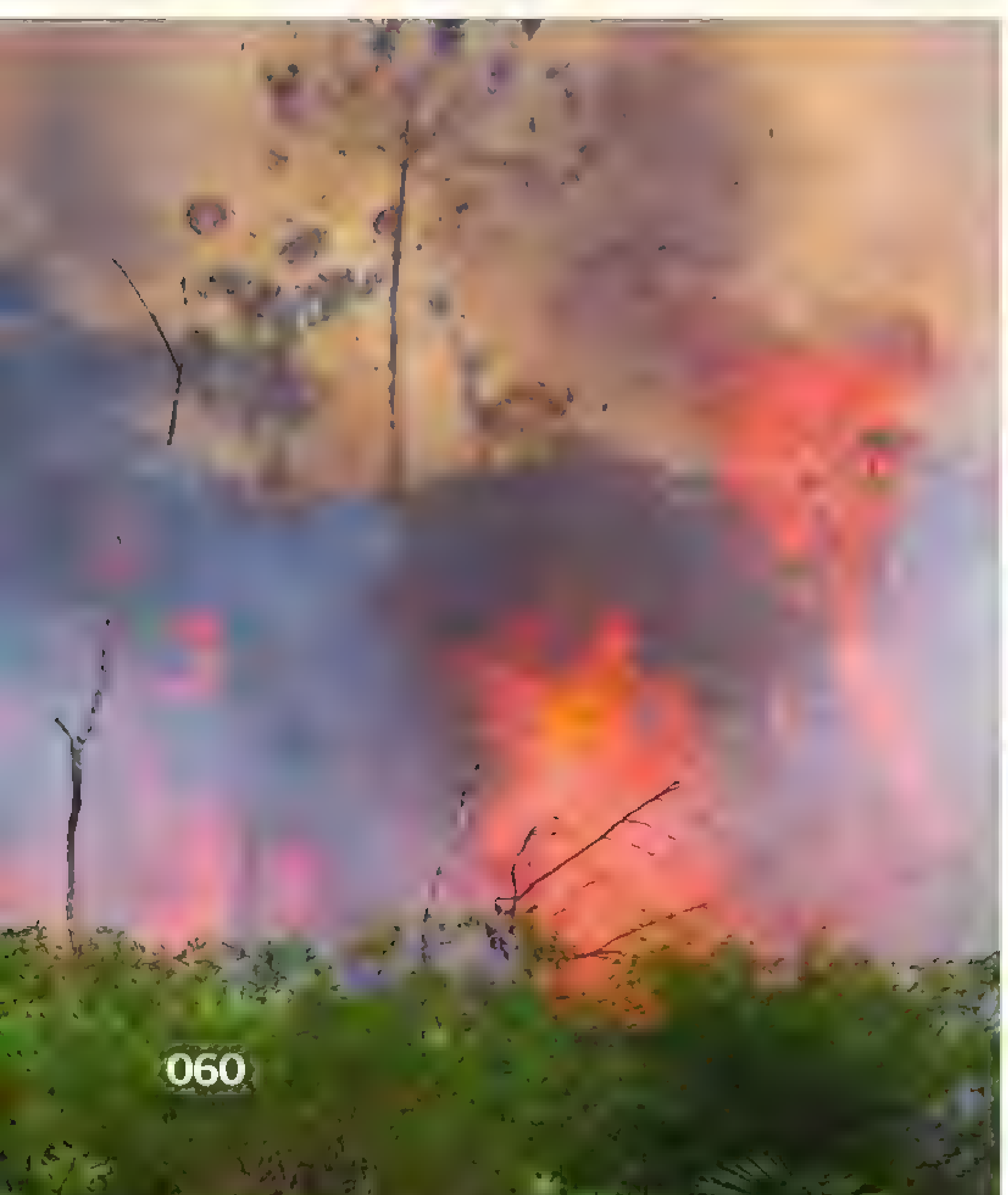
Trees that were planted 50 years ago in a bid to bring the forests back to the island nation are now struggling as the changing climate continues to fluctuate and winters become milder. To combat this, Iceland's foresters are turning to science to grow, study and select the optimum species that can survive and thrive to provide all of the benefits of reforestation. The saplings are raised in vast greenhouses where all parameters can be controlled to give them the best start in life.

Where Iceland is turning to precise science, huge swathes of the Amazon are relying on good old-fashioned natural selection as a key reforestation technique by using a method known as 'muvuca'. A Portuguese phrase to describe a lot of people in a small place, muvuca involves scattering a dense and thorough mixture of thousands of native seeds across cleared forestland. While many seeds may not

When complete, the Great Green Wall will span 8,000km across the African continent

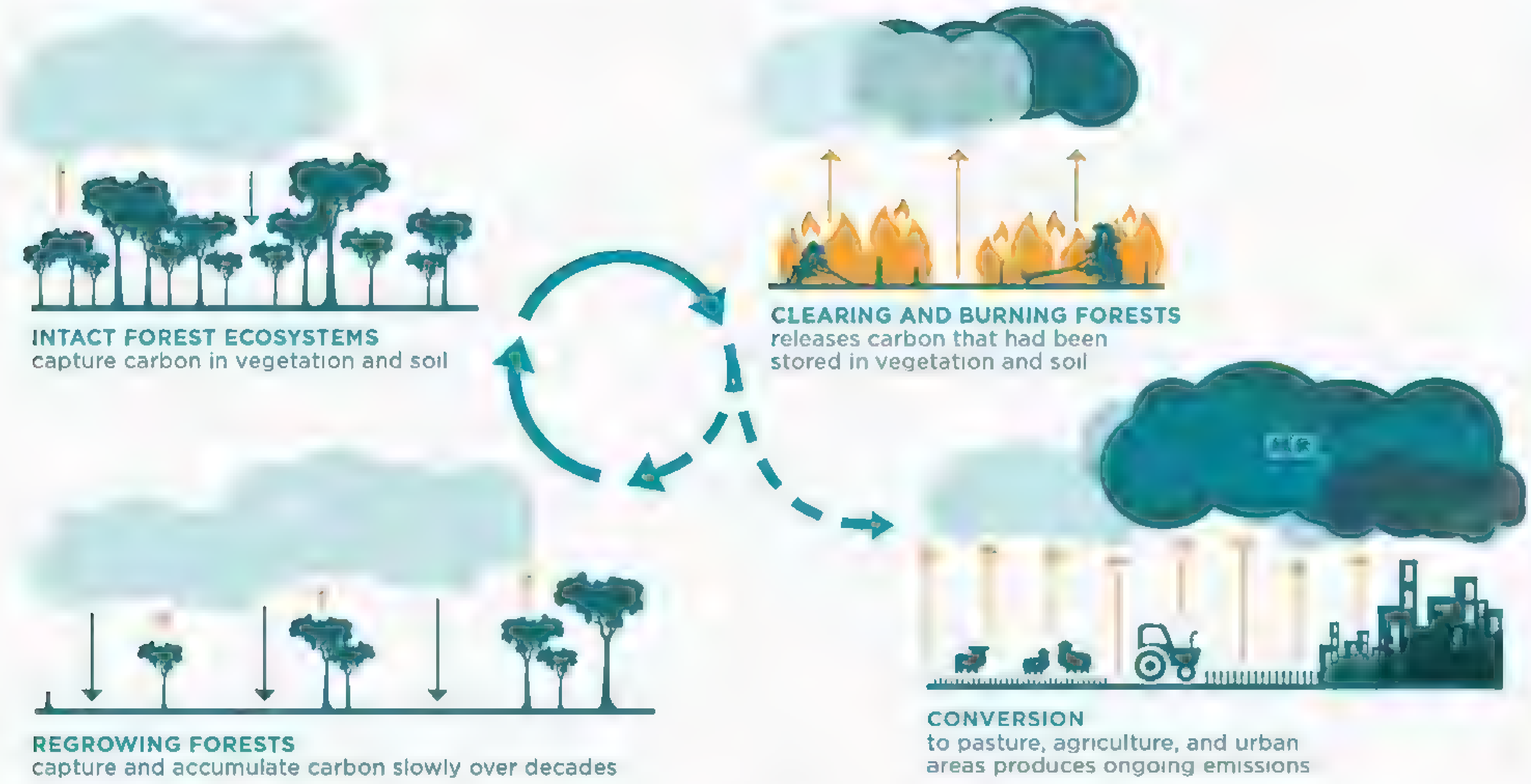

Planting brings work and livelihoods back to areas that were previously under threat from desertification

To cope with the demand for agriculture and livestock vast areas of rainforests are cleared by burning



Fighting climate change

Deforestation releases carbon dioxide into the atmosphere – reforestation captures it

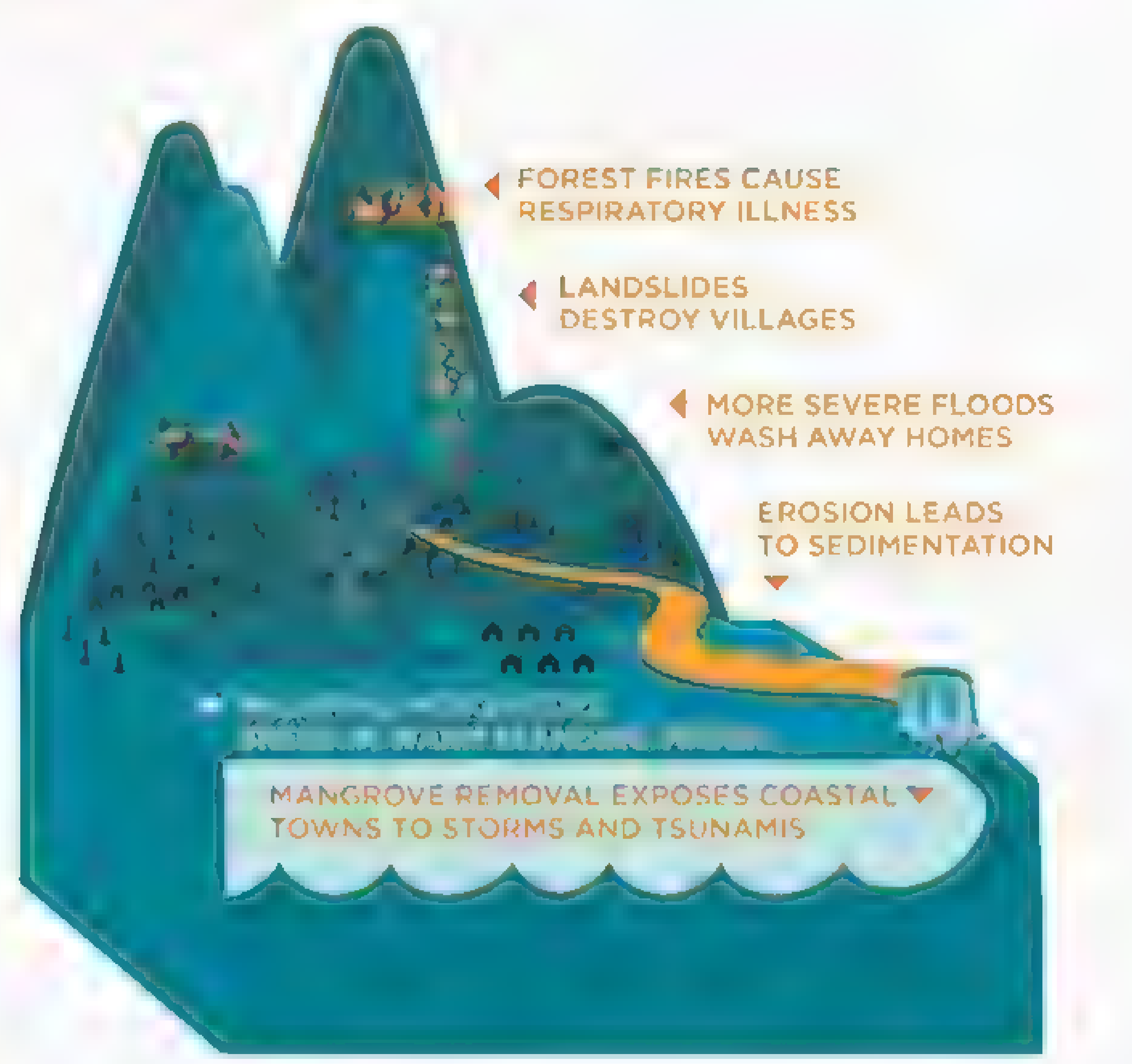


Green benefits

Healthy forests provide a number of benefits to local communities

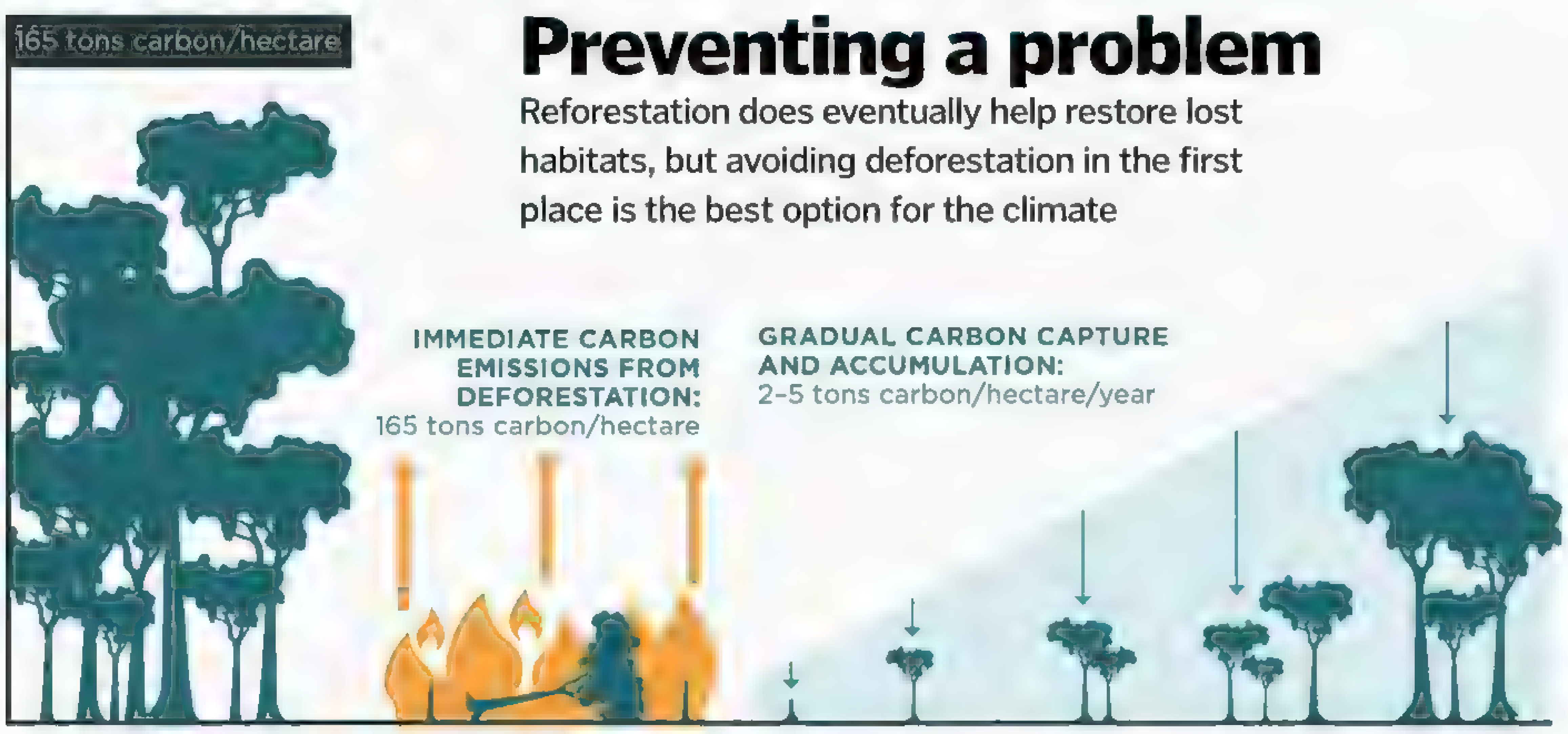
INTACT FOREST

DEFORESTATION



Preventing a problem

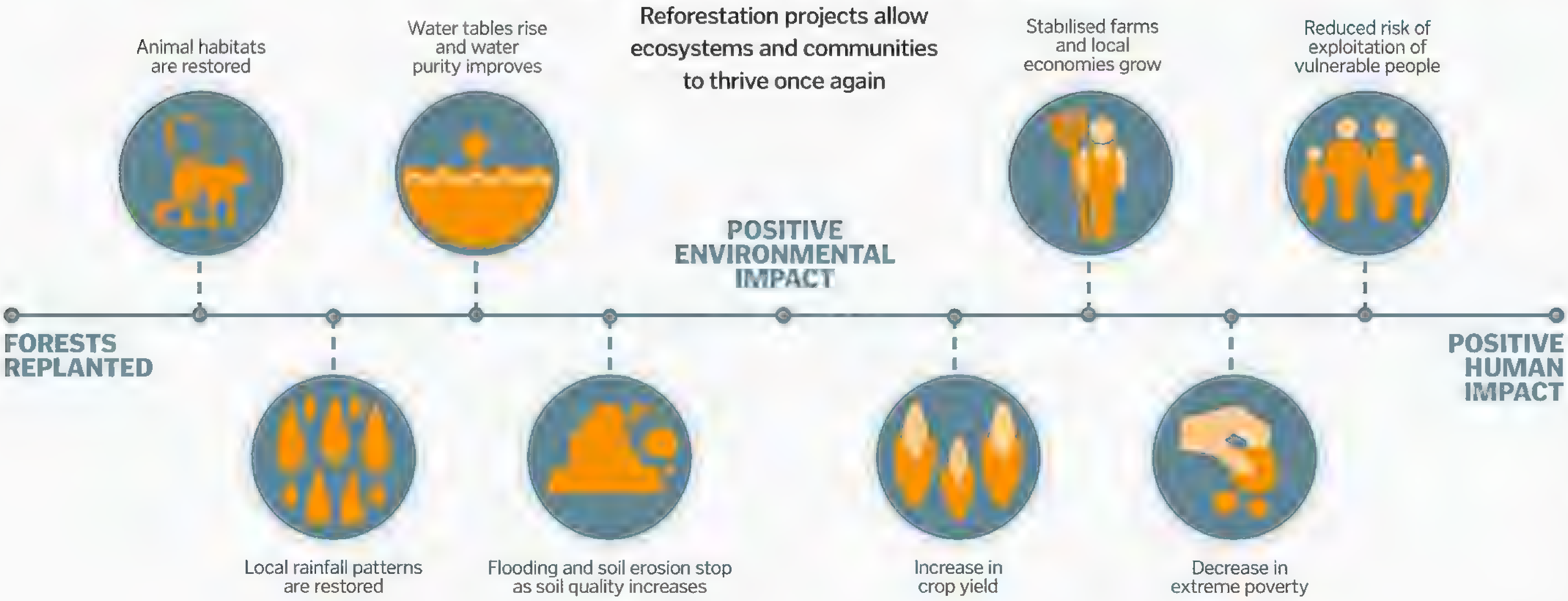
Reforestation does eventually help restore lost habitats, but avoiding deforestation in the first place is the best option for the climate



Data source: Adapted from Goodman and Herold 2014

Benefits of reforestation

Reforestation projects allow ecosystems and communities to thrive once again



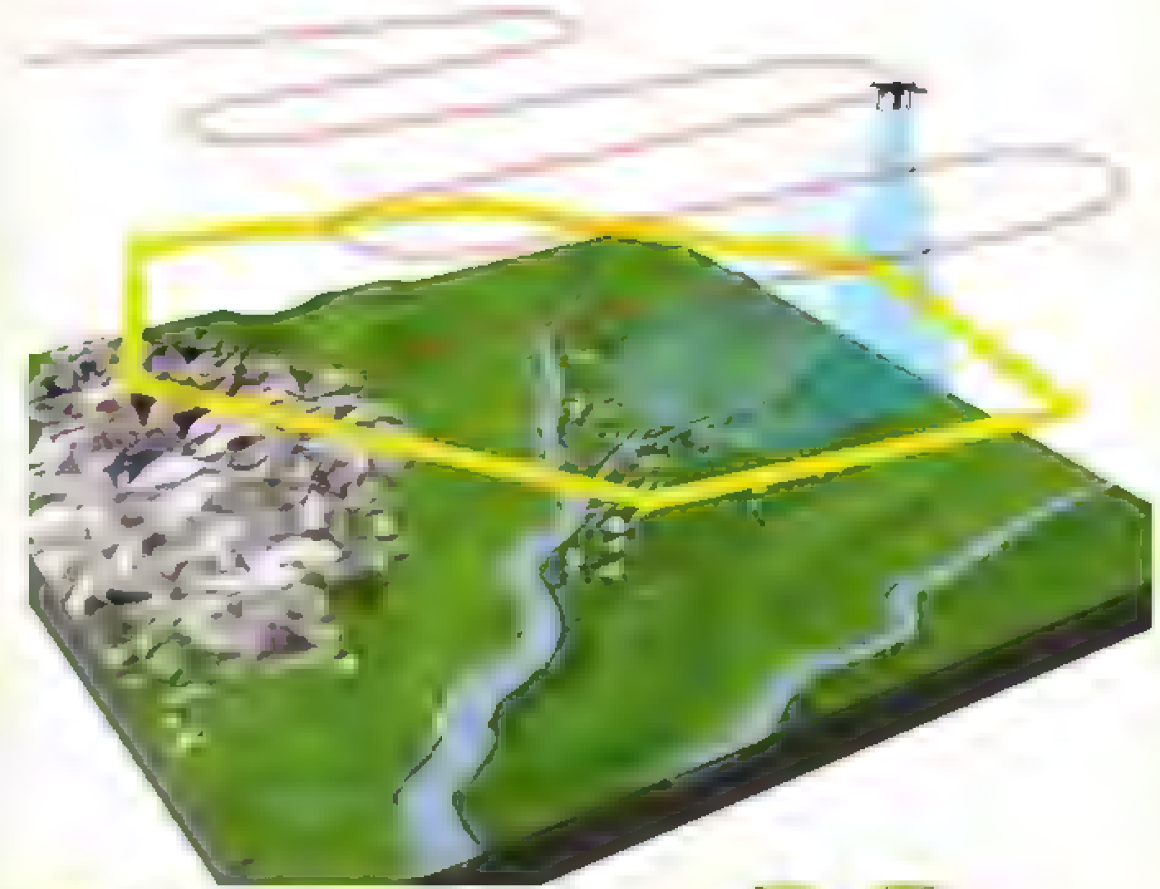
Urban forests

Like their rural forest counterparts, urban trees purify the air in their surroundings and provide shade and habitats for animals. They can also cool city air by between two and eight degrees Celsius, reducing the need for air conditioning by 30 per cent when planted near buildings. In a world where urban forests are becoming more important than ever, there are many initiatives worldwide aiming to bring more trees to city life.

London's Garden Bridge was one such proposed project, but something that has been brought to reality is Milan's Vertical Forest. Designed by Boeri Studio Architects, the two high-rise residential buildings are planted with 23,000 trees and plants specifically selected and placed for their physical properties. They wanted to make the forest an integral part of the architecture as well as having a functional role in reducing city pollution and absorbing carbon dioxide.

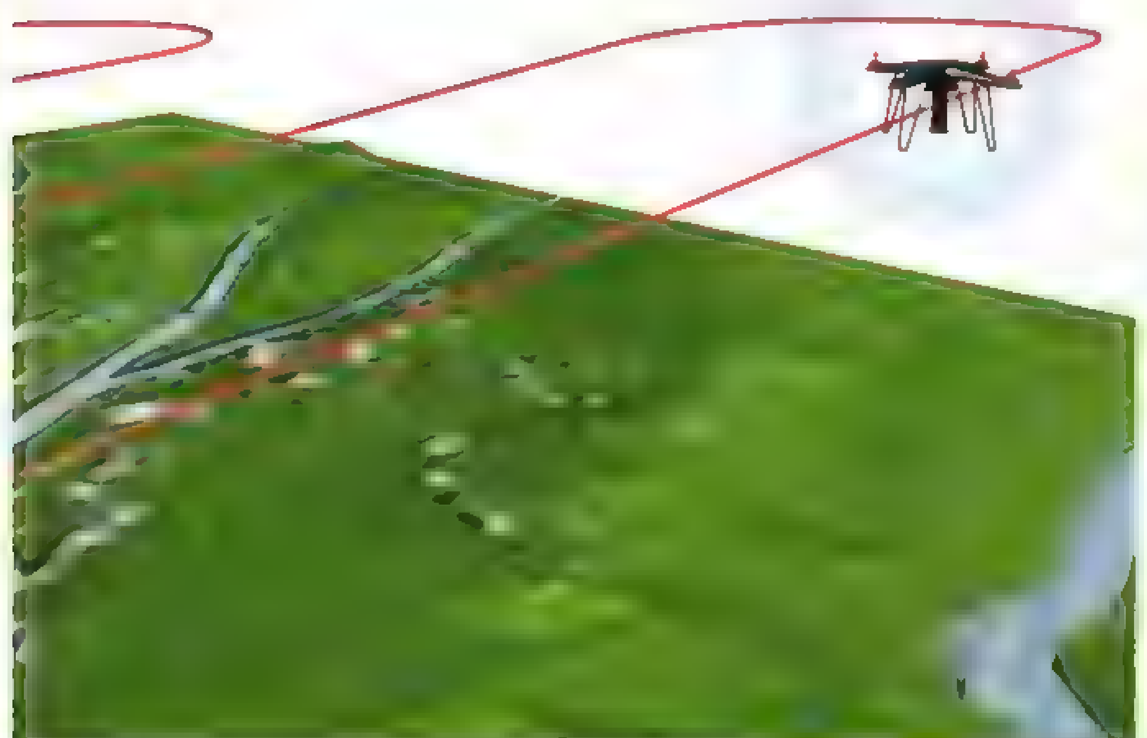
Drone reforestation

How cutting-edge technology is helping to boost green spaces by sowing seeds from the air

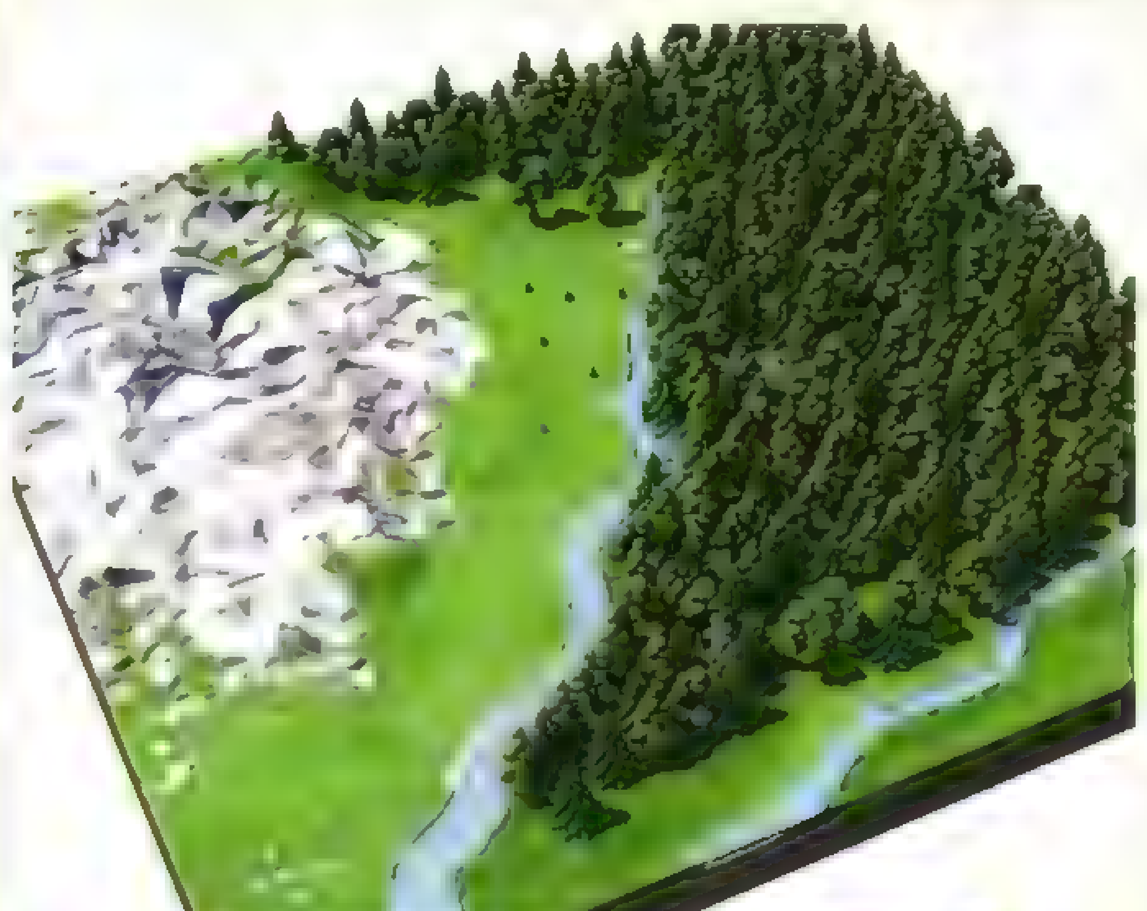


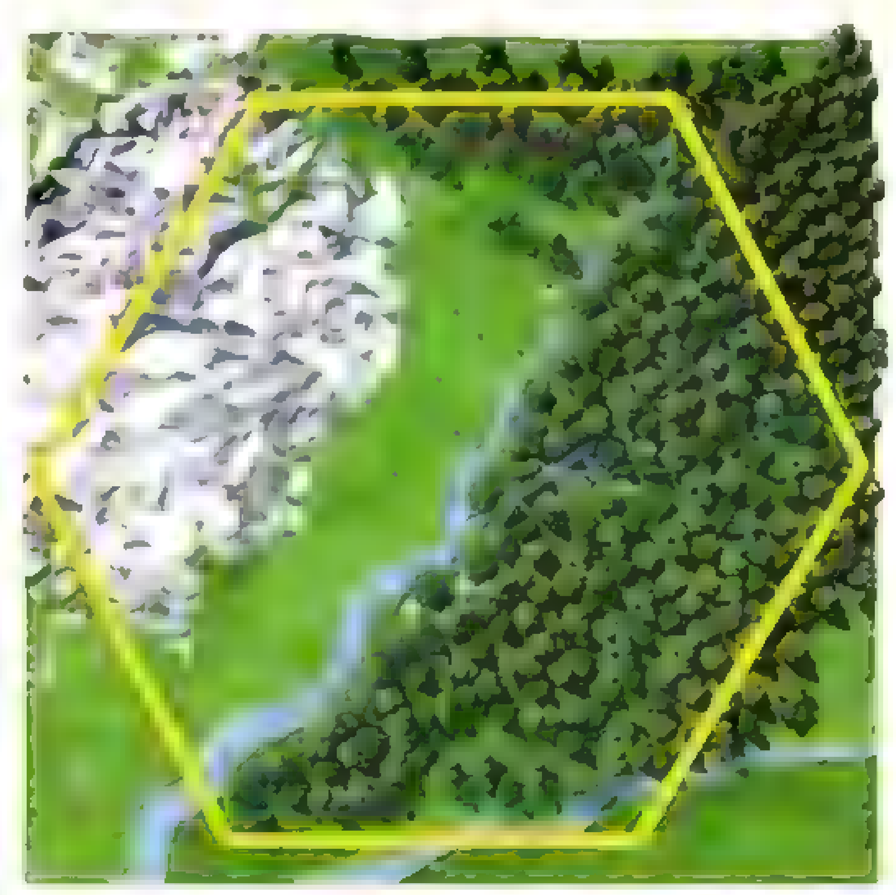
1 Choose the area Drones are used to scan key regions from above and select areas for reforestation.

2 Mapping As much data is gathered from the area as possible, including surface topology, soil type and obstructions.



3 Planting Collected data is used to generate a precise planting pattern. Biodegradable seed pods are sown from a specialised drone.





4 Monitoring the growth Similar to the mapping phase, the area is monitored via drone to build a picture of how the seeds and saplings are growing.

5 Scaling up Data is analysed to prepare for the next round of planting. Using this method it's possible to reforest large expanses of woodland.

DID YOU KNOW? *There are about 3.04 trillion trees on Earth, on every continent but Antarctica! That's 422 trees for each person*

take hold, the strongest and sturdiest will thrive and the result is a natural, organic forest where plants compete for resources among themselves.

In contrast to more traditional methods of raising and planting individual saplings – which is time consuming, expensive and by no means foolproof – the muvuca method allows for simple sewing and natural growth.

In one of the largest Amazonian reforestation schemes ever attempted, Conservation International is attempting to restore 30,000 hectares – corresponding to planting 73 million trees – of forestland using seeds from over 200 native species provided by seed banks supplied by local seed collectors. The muvuca can be sewn by hand, by air or by machinery and is a hugely versatile and diverse way of raising new native woodland.

> "The Great Plains 'shelterbelts' were one of the most successful environmental projects in US history"

The crusade to restore precious forests is not a modern concern; historically there has been great demand for trees to help with various issues. In the 1930s, America's Midwest was experiencing severe drought and sand storms that were crippling agriculture known as the Dust Bowl. President Roosevelt's solution was a simple one: plant 'shelterbelts' across the Great Plains. These were bands of trees that ran along the exposed boundaries of fields and roads, acting as windbreaks and trapping soil and nutrients with their roots.

By 1942, trees had been planted in their millions – stretching from North Dakota to Texas – in what is still one of the most successful environmental projects in US history. The effects of the drought were lessened, the dust storms reduced and gradually agriculture could resume.

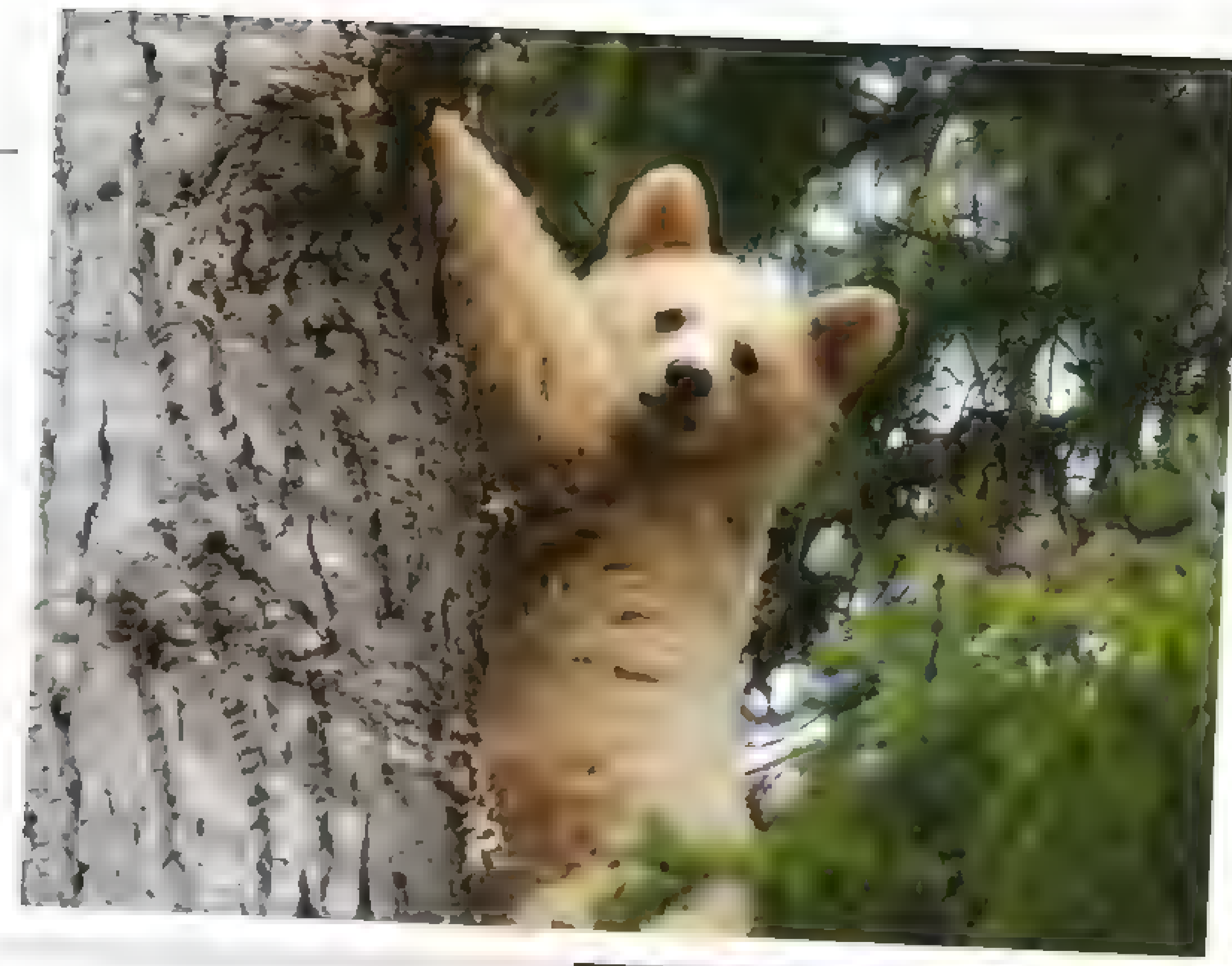
Reforestation on a global scale is a huge undertaking, and although the forests are still disappearing, the good news is that with the right application of knowledge reforestation works. You can help towards reforestation efforts in a few different ways. First of all, be sure to check where the timber you buy comes from and endeavour to use sustainable sources. You should also avoid products containing palm oil to help to reduce demand for this crop, which is causing devastating land clearances. There are also many charities out there dedicated to planting trees with your donations. There is even a search engine – Ecosia – that uses its advertising revenue income to plant trees, so you can help reforest the planet with essential life-giving trees while you search the web.

Above: A six-year project in the Brazilian Amazon – the world's largest rainforest – aims to plant 73 million trees by 2023

Areas shown in red highlight the extent of deforestation across South America between 2000 and 2012

What is a spirit bear?

How these pale-pelted mammals turn their colouring to their advantage



Due to the recessive nature of the spirit bear gene mutation, two black bears with the gene can produce spirit bear offspring

If you go down to Canada's Great Bear Rainforest, you're sure for a big surprise. Located at British Columbia's northwestern coast, Canada, are dense forests spanning 21 million acres. Aptly named the Great Bear Rainforest, this Amazon of the north is home to some truly unique bears. American black bears are among the most common species, however only in the Great Bear Rainforest have they evolved with a different coloured coat. They are known as Kermode, or 'spirit', bears.

Traditionally sporting black fur, it's estimated that there could be as few as 100 left. The change in colour is thanks to a rare genetic variation in a gene called MC1R, which codes for a protein that sits on the surface of melanocytes, cells that produce melanin for colouration. This mutation in the gene is what causes the melanin to appear white instead of black. Though these bears are often mistakenly thought of as being albinos - when there is a lack of melanin in the fur and eyes - this is not the case as, like black bears, they have a dark nose and paws.

Researchers have found that thanks to their unusual appearance they are 30 per cent more effective in hunting during the daytime compared to their darker counterparts. This efficiency may have been one of the reasons they have maintained their genetic lineage since the mutation was first expressed. It is thought that due to the isolated nature of the forests the gene has not spread further than the bears residing in Great Bear Rainforest. Another explanation for their continued presence has been selective mating, meaning that spirit bears have a preference for other spirit bears and so the genetic mutation is passed down from generation to generation.

Bear profile

Kermode bear
Ursus americanus kermodei

Weight: 80–200kg
Length: 1.2–1.9m

Found only in the Great Bear Rainforest, these bears build their winter dens beneath the forest's dense canopy.

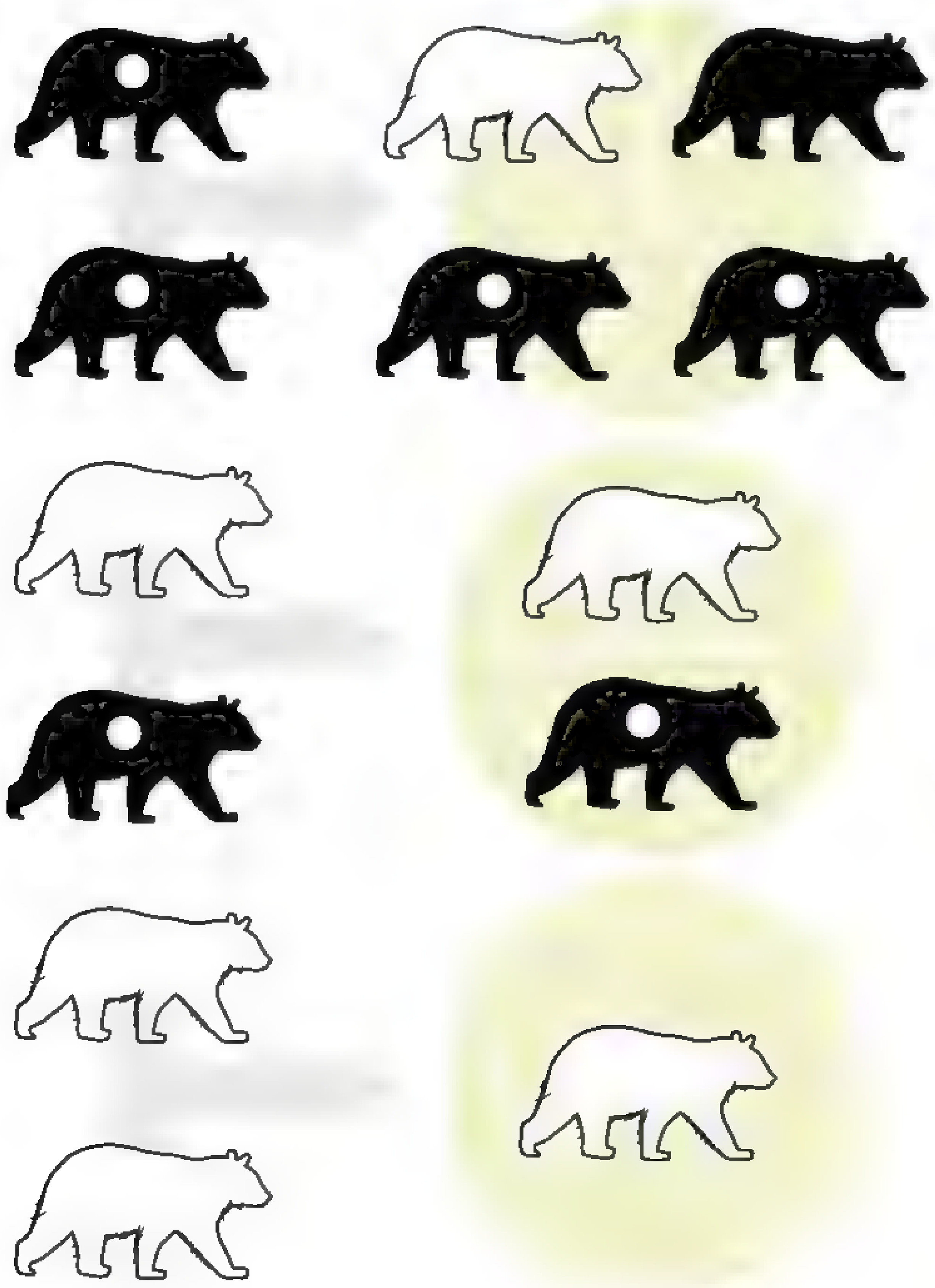
A spirit bear's main source of food is fish, in particular Pacific salmon. Like all black bears, spirit bears are omnivores and therefore will eat fruits, nuts, plants and even carrion (rotting flesh) when fish is in short supply. Scientists think their white coats act in their favour when hunting for fish during daylight as they are harder for the fish to spot above the water.

25 years in the wild

The biggest threat to this unique bear is disruptions in the coastal ecosystem. Declining salmon populations, tree logging and migrating grizzly bears could threaten this isolated species.

Creating a spirit bear

What is the likelihood of a bear cub being a black or spirit bear?



25%
In the event two black bears with the spirit bear recessive gene mate, there is a 25 per cent chance their offspring will be a spirit bear, a 25 per cent chance of being a black bear without the recessive gene, and a 50 per cent possibility of a black bear with the recessive gene.

50%
Should a spirit bear and a black bear carrying the recessive gene produce offspring, there is an even chance of them producing a spirit or black bear with the recessive gene.

100%
A paring of two spirit bears would guarantee another spirit bear offspring.

Spirit bears feast on the flesh of fresh pacific salmon during spawning season

Spirit bears can only be found in the Great Bear Rainforest in British Columbia, Canada

Down the Pacific plughole

What created Thor's Well and where does all the water falling into it go?

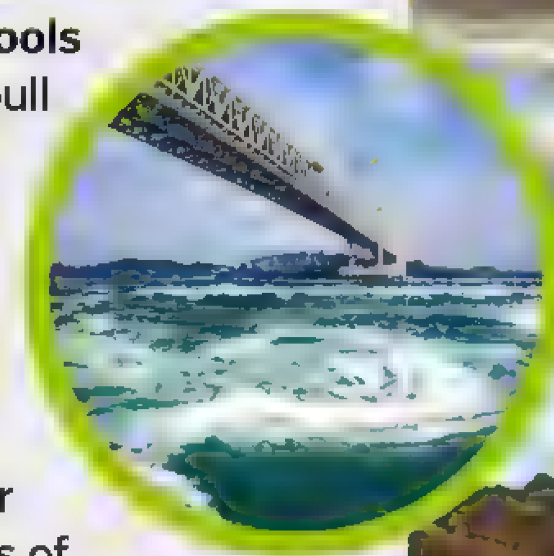
Along a large, forested headland of Oregon, US, sits a sinkhole that appears to drain away the water of the Pacific Ocean. Named after the Norse god of thunder, Thor, the legend of the well says that in a fit of rage, Thor himself struck the Earth, creating its six-metre depth. However, the creation of this ominous formation is really thanks to the waves that fall into it.

Oregon's coast, in particular the Cape Perpetua, consists of dark basalt, an oceanic igneous rock that is formed from molten magma beneath the Earth's mantle spewing into the ocean. Due to constantly flowing and colliding waters from the ocean and underground waters, subterranean caves and cavities are carved out of the basalt. It is the formation of such caves that offer the most comprehensive explanation for the ability of Thor's well to continually swallow the incoming salt water without filling up. With ocean water eroding the ceiling of the underwater cave from above it eventually collapsed, carving out the entrance of the well. This, however, doesn't explain its ability to remain empty, as a cave beneath the ground would quickly fill up.

Several theories have been suggested to explain the missing water, including a network of cavernous tunnels transporting the water elsewhere or ejecting it straight back into the ocean. One of the obvious ways the well removes infiltrating water is through fountain displays that occur as the water and air pressure builds up in the cave. When a critical pressure is reached the seawater is thrust back out of the opening in a spectacular eruption.

DID YOU KNOW? *The highest waterfall in the world is the Angel Falls in Venezuela, which measure 979 metres*

5 FACTS ABOUT WEIRD AND WONDERFUL WATER

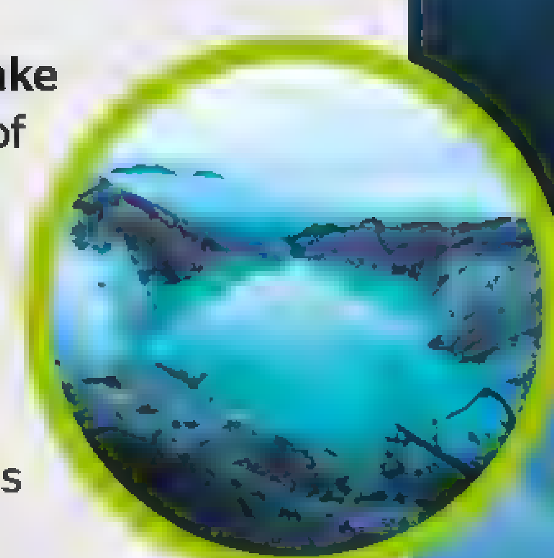


1 Naruto Whirlpools Thanks to the pull of the Moon, whirlpools form along the Naruto Strait in Japan. During the spring and autumn seasons this water can rage at speeds of up to two kilometres per hour, creating larger whirlpools.

2 Fairy Pools In the highlands of Scotland is a series of small waterfalls that make up the Fairy Pools. The water that fills the pools is crystal clear and is often referred to as some of the most pristine in the world.

3 Blood Falls Bleeding through the ice in Antarctica's McMurdo Dry Valley, crimson water cascades into the sea below. Trapped beneath around 0.4 kilometres of ice, this iron-rich water travels to the glacier opening and oxidises, turning blood red.

4 Cenote Ik-Kil The Ik-Kil In Mexico is a subterrean swimming hole formed by the collapse of its limestone ceiling. The water within this well reaches depths of over 40 metres.



5 Kawah Ijen Lake Upon the top of the Kawah Ijen volcano in Indonesia is a kilometre-wide electric blue lake. Its vibrant colour is thanks to high quantities of sulphur and several dissolved metals within the water.


Bird lungs are small and rigid, but they aided by expanding air sacs

How birds breathe

Discover the unusual respiratory system that helps birds fly the distance

When mammals breathe, air travels into the lungs and then back out again in a single breath, providing only one chance to transfer its oxygen into the blood. Birds, however, take two breaths to process one lot of air, meaning it passes through the lungs twice for a double dose of oxygen.

This efficient method of respiration is the reason birds are able to fly long distances despite their small lungs. The lungs get help from air sacs – most birds have nine – that work like bellows to pump air through the lungs. These sacs also regulate their body temperature and help aquatic birds to float on water.

Air efficiency

A double dose of oxygen with every gulp of air

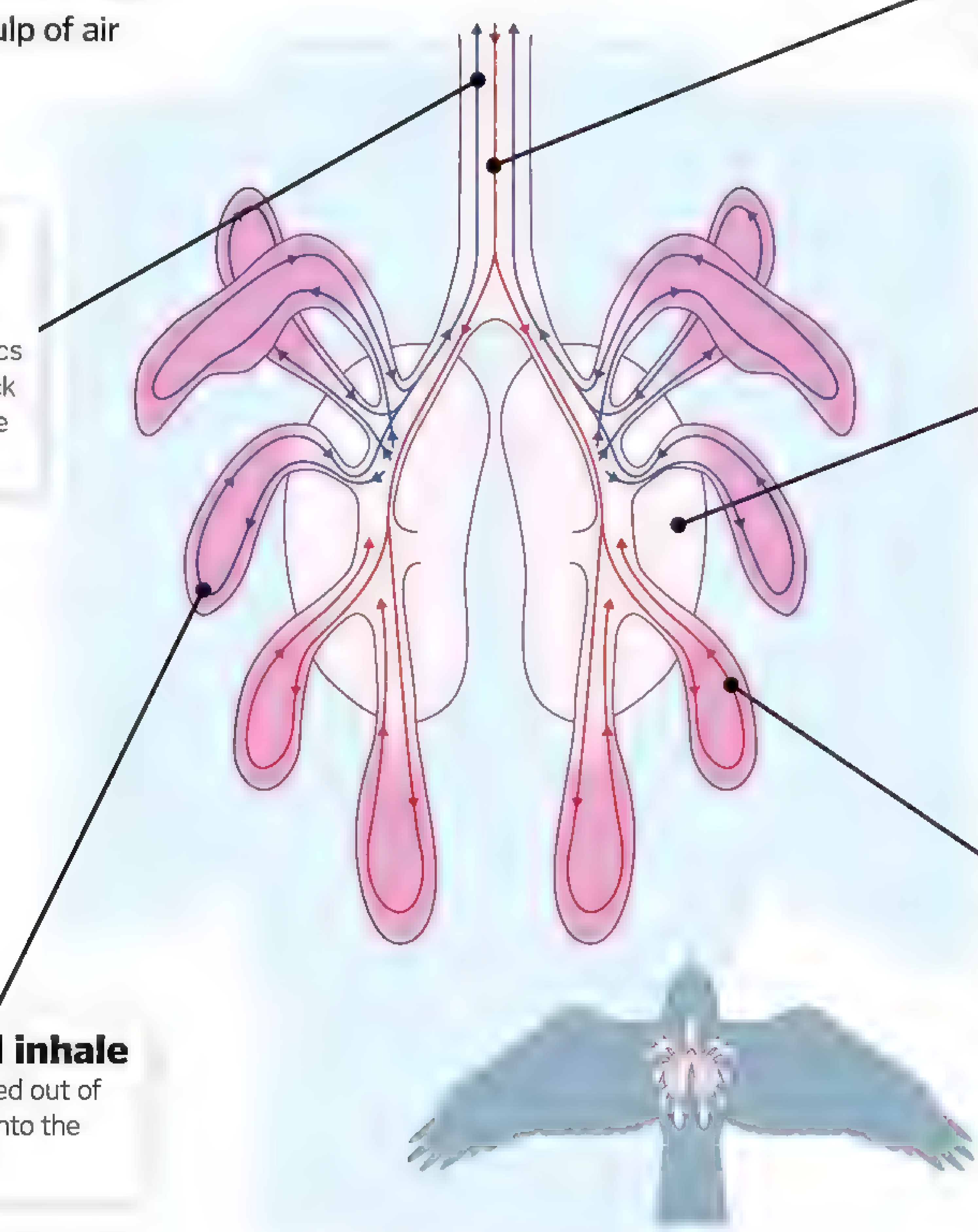
1. First inhale
The air enters through the trachea to the lungs and then into the rear air sacs.

2. In the lungs
Here, oxygen in the air is exchanged for carbon dioxide waste.

3. First exhale
The air moves from the rear air sacs back into the lungs.

4. Second inhale
The air is pushed out of the lungs and into the front air sacs.

5. Second exhale
The air leaves the front air sacs and travels back out through the bird's trachea.



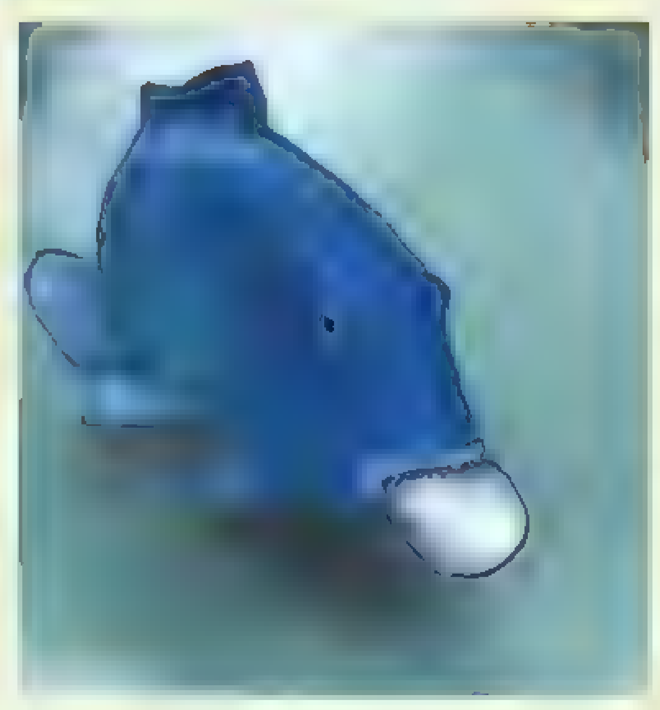
© Getty; Illustration by Adam Marciniewicz

Creative creatures

Meet the amazing animals that have learnt to use tools

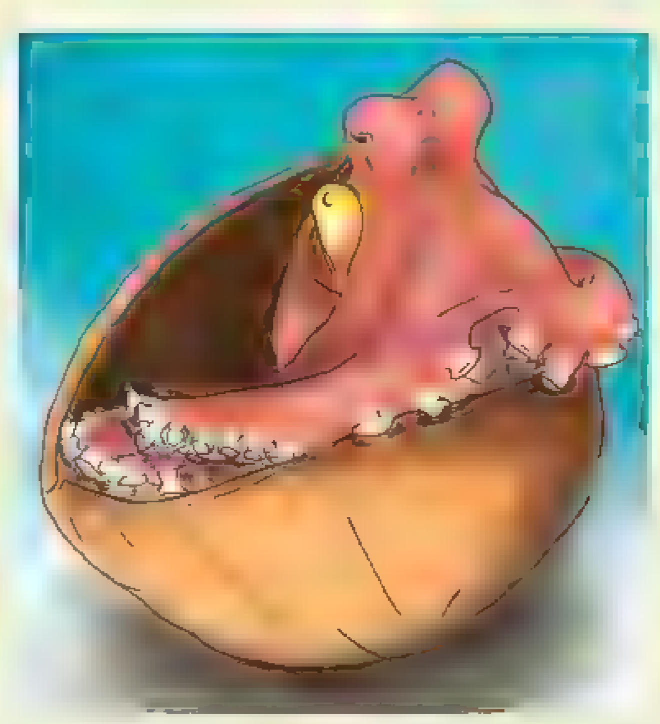
Chimpanzees
Chimps can adapt twigs to fish termites from their nests and absorb water to drink from narrow holes in trees. They also use rocks as weapons and to hammer open nuts. Some have even been seen crafting spears.

Crows
Certain species of crow have been observed using sticks to extract food and transport it back to their nests. They even seem to develop a fondness for particular tools, with hooked twigs often a favourite.



Tusk fish
As revealed on *Blue Planet II*, this clever species of fish has worked out how to smash open clams on pieces of rock or hard coral in order to get to the juicy food within, a process that can take minutes or hours.

Crocodiles
In a first for reptiles, crocodiles have been observed balancing sticks on their snouts to lure unsuspecting birds looking for nest-building materials into their reach, so that they can eat them.



Octopus
These soft-bodied molluscs use coconut shells and other such debris that they find on the sea bed as protective armour, hiding inside as a predator approaches and then rolling away when it swims off.

The world's largest waterfall

Discover why you might struggle to visit the tallest waterfall on Earth

With their staggering power and awe-inspiring beauty, waterfalls are one of the most popular natural wonders to visit on Earth. However, if you were hoping to see the world's tallest waterfall, then you'd better pack your diving gear.

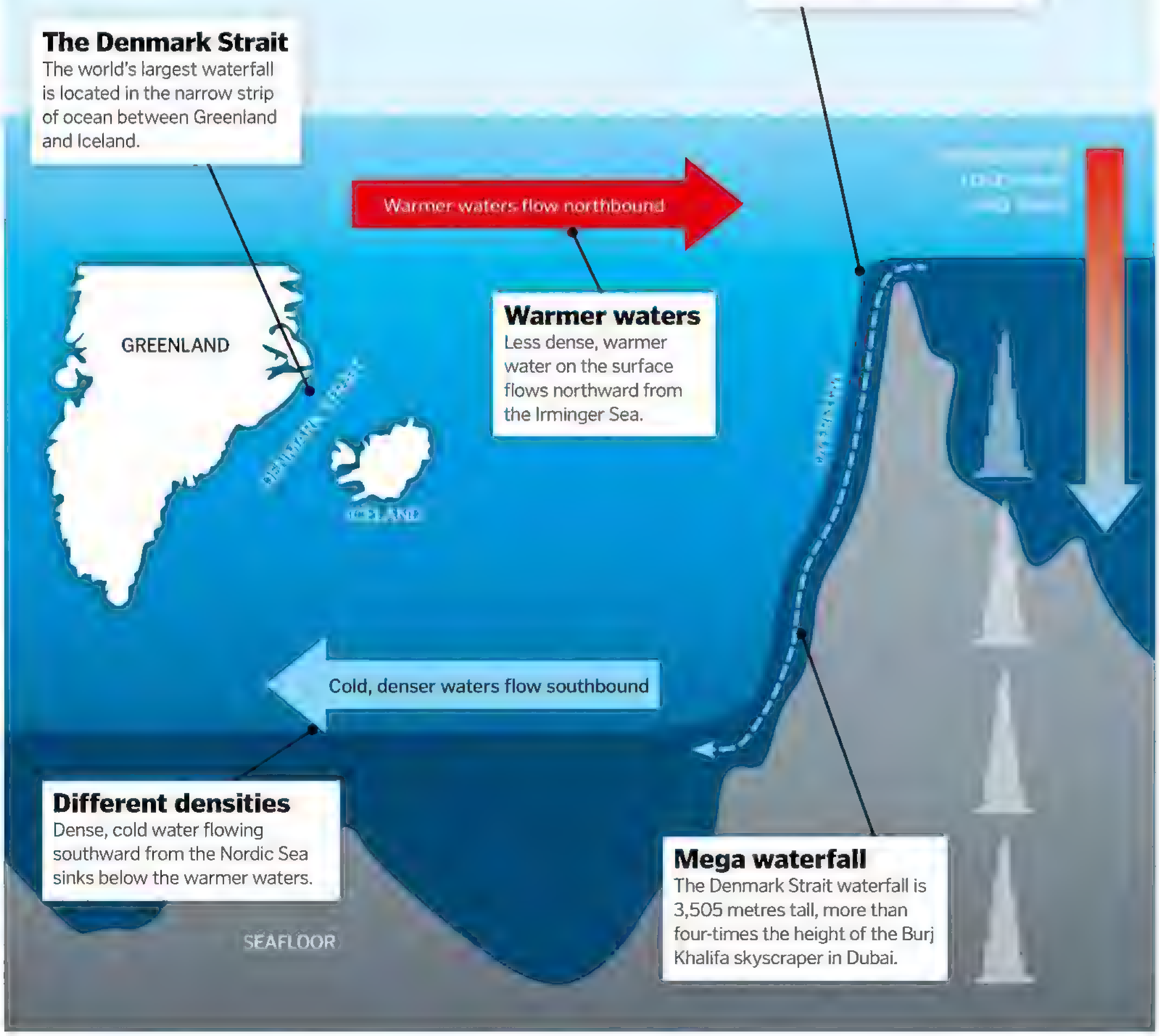
While most people think of Venezuela's Angel Falls as the largest waterfall in the world, that title actually goes to a ridge beneath the Denmark Strait. Here, starting 600 metres below the water's surface, is a waterfall that plunges 3,505 metres to the seafloor.

This underwater cascade is made possible due to differing water densities. In the strip of sea between Greenland and Iceland, cold waters from the north meet warmer waters from the south. The molecules in cold water are less active and more tightly packed together than those in warm water, making them much denser. Therefore, when the two meet, the cold water sinks below the warm water, where it flows over an enormous ridge to create an undersea waterfall.

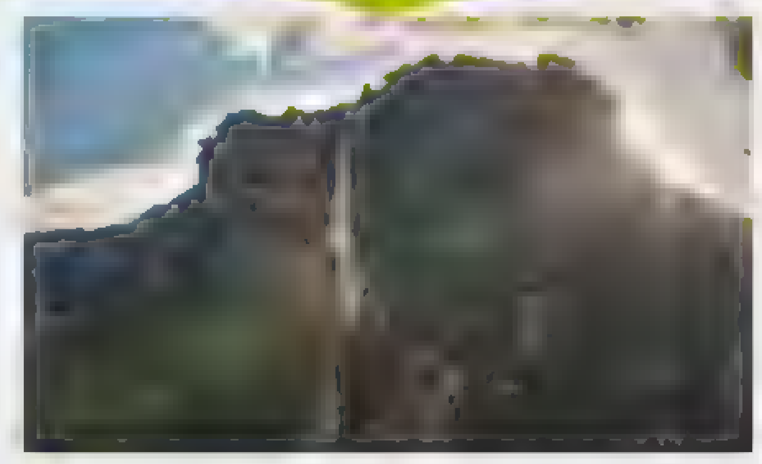
As well as being incredibly tall, the Denmark Strait waterfall is also very wide, stretching 160 kilometres across. It really would be an incredible sight to behold on land, but unfortunately, as it is already surrounded by water, the falls are completely undetectable without scientific equipment. So maybe hold off on packing your bags just yet!

Under the sea

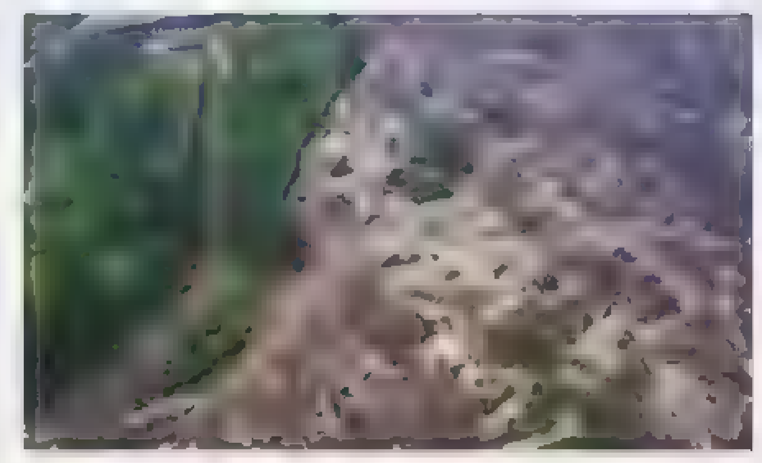
How an enormous waterfall flows beneath the waves



5 WHOPPING WATERFALLS



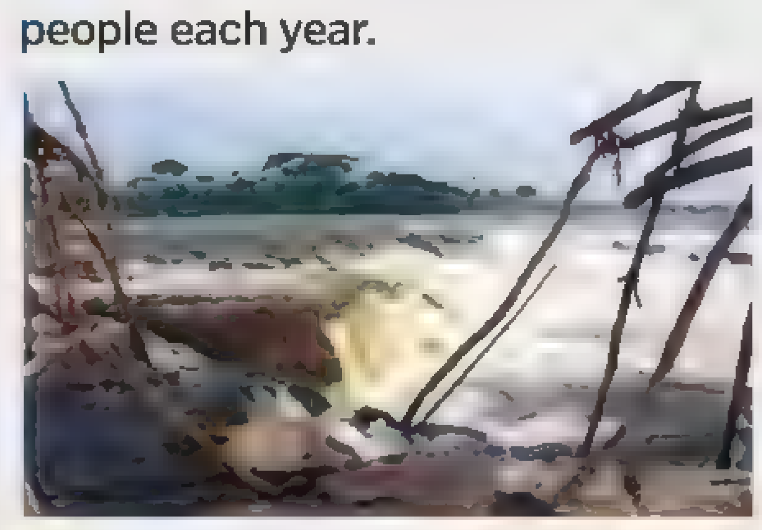
1 Angel Falls – Venezuela
The tallest waterfall on land is 979m tall, three-times shorter than the Denmark Strait falls.



2 Inga Falls – DR Congo
25,768m^3 of water flows over the world's largest waterfall by volume every second – equating to over 2.2bn m^3 a day!

3 Khone Falls – Laos
The widest land waterfall in the world measures an incredible 10,783m across.

4 Niagara Falls – Canada-US
The world's most-visited waterfall attracts around 28 million people each year.



5 Boyoma Falls – DR Congo
The fastest waterfall has a mean annual flow rate of 17,000m^3 of water per second.

HOW WE WILL FIX THE PLASTIC PROBLEM

Plastic waste is choking the planet. What can we do to clean the trash from the oceans?

Words by **Laura Mears**

Somewhere between Hawaii and California, a vast inflatable coastline sweeps through the sea. Beneath a 600-metre-long float, a three-metre deep skirt rakes the ocean. Forced along by wind and waves, it moves faster than the currents, bending as it travels to form a U-shaped net. Fish dive beneath to escape its advances, but as the system roams the water it gathers a strange catch. Braving gales and storms and resisting the corrosive effects of sea salt, System 001 sends signals to satellites overhead and boats close by to collect a haul unlike any other. This net is trawling the great Pacific Garbage Patch, and its job is to clean up the sea.

The Pacific Garbage Patch is a trash vortex; a swirling gyre of waste caught up in ocean currents. While not the literal island of rubbish sometimes described in the media, its waters are strewn with small chunks of floating debris. Churned by the action of the waves, the pieces bob up and down in the water column, circulating with the currents. Invasive species hitch a ride on the travelling plastics, making their way to waters nature never intended for their occupation. Sea birds, marine mammals and fish mistake the floating chunks for food, filling their bellies with indigestible trash. The pieces that remain wear away under the relentless rocking, rubbing microscopic plastic splinters and toxic chemicals into the water.

> "The Pacific Garbage Patch is a trash vortex"

Deployed on 16 October 2018, System 001 aims to clear half of the rubbish from the Pacific Garbage Patch over the next five years. It is the first of a network of 60 and the result of more than 270 scale model tests and six prototypes. Pushed along by natural forces and equipped with solar-powered electronics, System 001 quietly follows the flow of the water. It's got lights and GPS to warn sailors, and it moves slowly enough that fish

The plastic problem

How does plastic get out into the environment?

1 Constant consumption
The world produces 300 million tons of plastic each year, half of which we use just once before discarding.

2 Contaminated water
Over 110,000 tons of microplastics wash over agricultural land in North America and Europe every single year.

3 In the laundry
Acrylic clothes release over 700,000 plastic fibres per 6kg wash. Polyester releases nearly 500,000.

4 Plastic per person
The average person in the EU makes 31kg of plastic waste every year.

5 Microplastic soup
There are more than 5 trillion pieces of plastic floating about in the oceans.

6 Rivers of rubbish
Our rivers carry around 100,000 rubbish trucks' worth of plastic waste out to sea each year.

7 Out to sea
12 million tons of plastic makes it out into Earth's oceans via rivers, beaches and drains every year.

8 On the beaches
For every mile of UK beach you can expect to find 5,000 pieces of discarded plastic waste.

have plenty of time to get out of the way. Plastic, on the other hand, can't escape: trapped between the inflatable float and the solid skirt, it has nowhere to go. Load by load, sea-going rubbish trucks will retrieve the waste and start to clear the ocean. If all goes well, the project could roll out across the globe to remove 90 per cent of our floating junk by 2040.

HOW DID WE GET HERE?

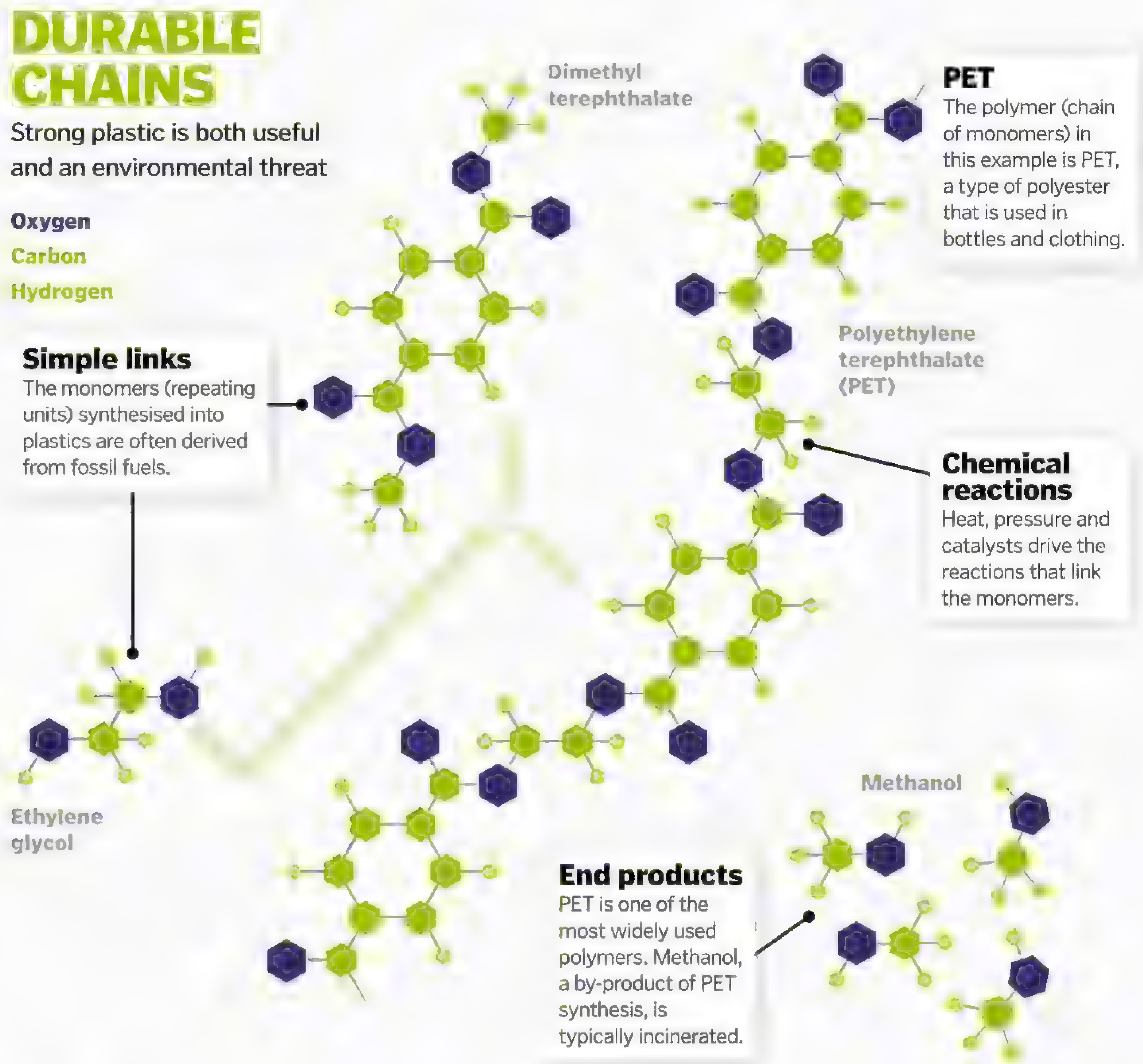
It's barely more than 100 years since Leo Baekeland invented the first fully synthetic plastic. Developed to insulate electrical wires at the tail end of the second industrial revolution, this new material was unlike anything seen before. Cheap to produce, resistant to heat and highly mouldable, it could be anything people wanted it to be, and its appearance kick-started a wave of chemical innovation.

All plastics have the same basic structure. Zoom in and most look like strings of pearls, with long, repeating chains that melt when they heat up and set hard as they cool. What makes them special is their versatility. We can extrude them into thin sheets, press them between rollers, blow them into bubbles, cast them like metal or vacuum mould them into 3D shapes. Changing the chemical building blocks of the chains can alter their flexibility, melting point and ability to resist chemicals. Additives between the chains can change their colour, make them fire-proof or kill bacteria, and adding branches to the chains can make them tangle, forming knots that don't melt and locking finished plastics into permanent shapes.

These incredible materials are cheap, clean and waterproof. They can be thick or thin, bendy or brittle, brightly coloured or completely clear. We can wear them against our skin, wrap them around our food and use them to construct everything from pens and tinsel to smartphones and spaceships. Plastics are strong enough to support buildings, light enough to fly and slippery enough to stop eggs sticking to frying pans. But these wonder materials are so cheap that we don't think twice about throwing them away.

> "Making paper produces more pollution than making plastic"

Today, we make 300 million tons of plastic a year, half of which goes straight in the bin. We waste 1 million plastic bottles a minute, half a million plastic straws a day and 4 trillion plastic bags every year. Of all the plastic we have ever made, nearly 80 per cent is in landfill or littering the natural world. Nearly a third of plastic packaging goes straight out to sea, where it will stay for several human lifetimes; enzymes made by living things can't touch the human-made chains that make plastic so strong and durable.



WHAT CAN WE DO?

The Ocean Cleanup project sits at the very end of the plastic economy, mopping up the river of waste pouring out of our homes and businesses. But, as System 001 scours the sea, people across the globe are stepping up to battle the plastic production line.

The biggest plastic-producing sector is packaging. There are bags, trays and films made from low-density polyethylene (LDPE); milk and shampoo bottles made from high-density polyethylene (HDPE); water bottles and cleaning fluid bottles made from polyethylene terephthalate (PET); plates, cups and cutlery made from polystyrene; insulated packaging made from expanded polystyrene; and bottle caps, crisp packets and ice cream tubs made from polypropylene. Across the world, we use an estimated 10 million plastic bags every single minute. To stem the plastic tide, it makes sense to start here.

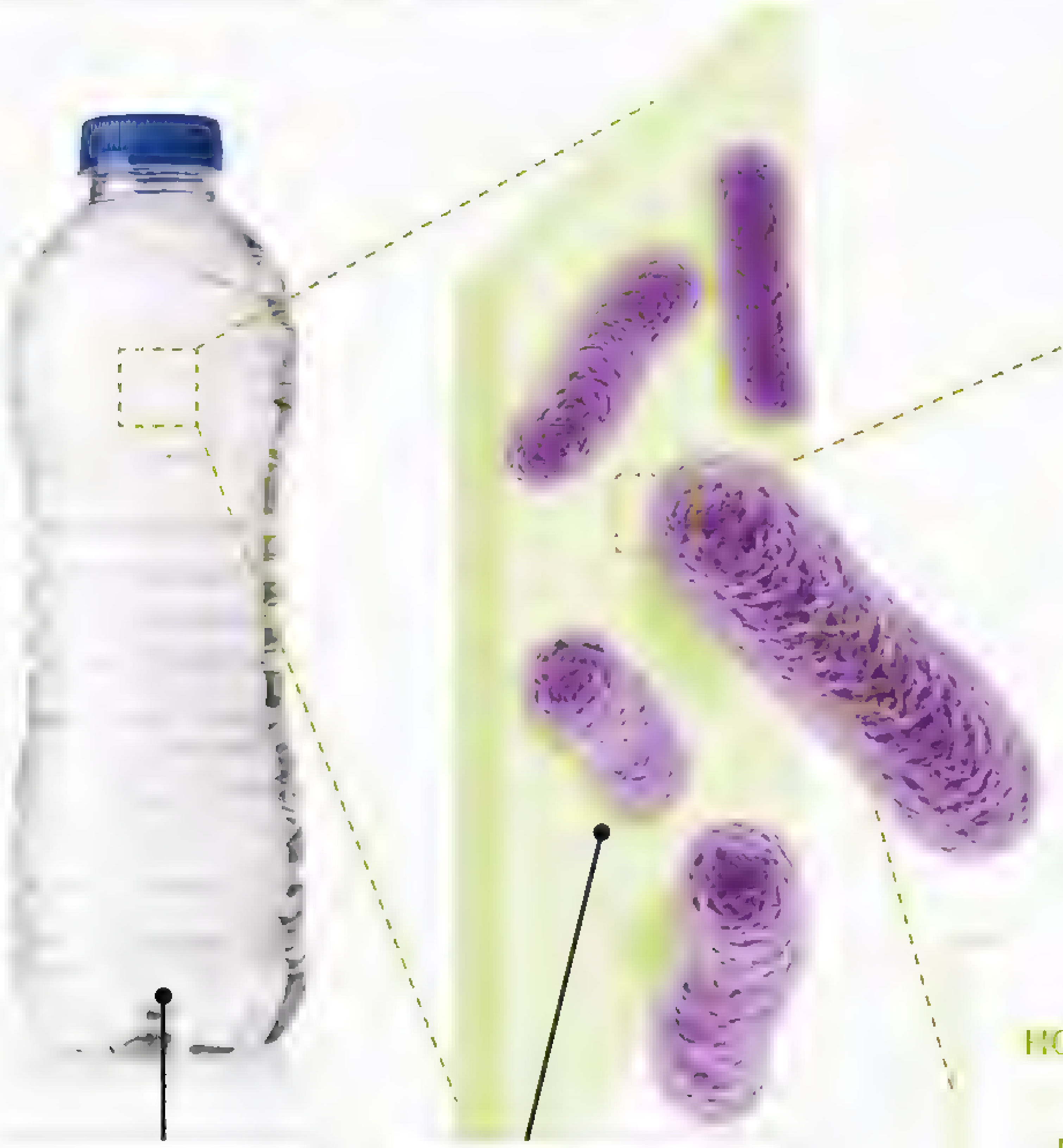
Since it launched in 2017, more than 50 countries have signed up to the UN Environment Clean Seas campaign. Single-use plastic is now firmly in the firing line, and countries across the world are phasing them out. Taiwan is ramping up to a total ban on single-use straws, cups and plastic bags, Zimbabwe plans to ban expanded plastic food packaging, and Kenya has already made plastic bags illegal; people found making, selling or using them face a fine of up to £30,000 (approximately $38,000) or up to four years in prison. They may seem drastic, but these tactics are working. In the UK, a 5p tax on single-use plastic bags has seen the number of bags used in England drop by more than 80 per cent.

Bags, straws and microbeads are some of the easiest targets; switching to non-plastic alternatives is cheap and simple. But when it comes to other single-use products like bottles, cutlery and coffee cups, the challenge is greater. One option is to replace plastics with traditional materials. We could use glass, metal, paper, card or jute (vegetable fibre). Yet, while recyclable, these materials aren't always better for the environment. Making paper produces more pollution than making plastic, and it also consumes more energy and more water. And, while glass production is more environmentally friendly, the containers themselves are heavy and bulky, racking up more pollution when products are eventually shipped out.

Creative start-ups are already experimenting with new options, including cutlery made from wheat, water bottles made from seaweed and

The bacteria that eat plastic

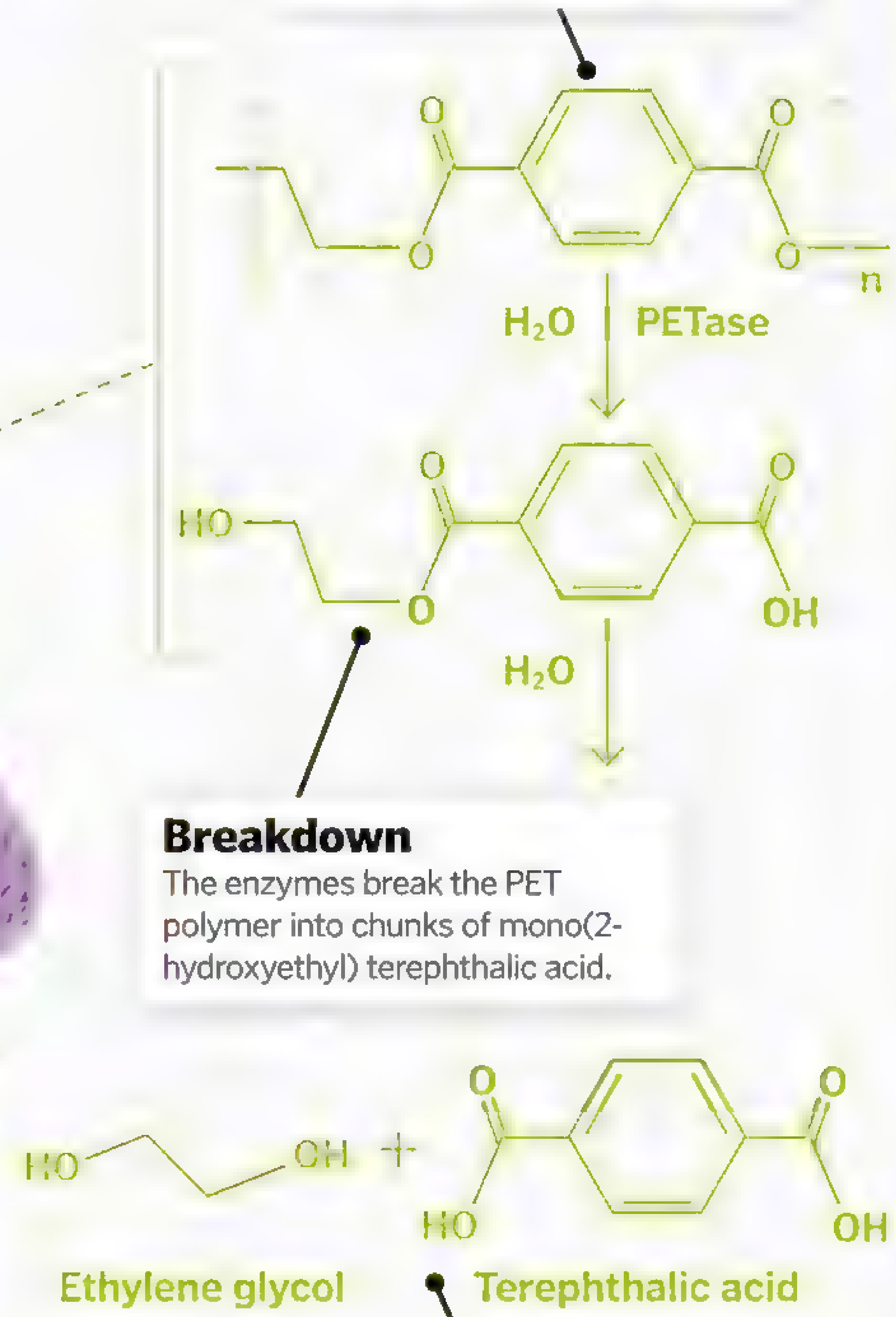
In 2016, scientists found a plastic-munching bug at a bottle recycling facility in Japan



PET
Polyethylene terephthalate (PET) is the kind of clear plastic used in drinks bottles.

Ideonella sakaiensis
Scientists discovered a species of bacteria that has evolved to use PET as food.

PETase
The bacteria makes enzymes called PETases, which break down the plastic polymer chains.



Breakdown
The enzymes break the PET polymer into chunks of mono(2-hydroxyethyl) terephthalic acid.

Digestion
The bacteria take up the chemical chunks and split them apart to make their own molecules.

WHAT IS PLASTIC?

Plastic polymers are long chains of molecules linked by carbon-carbon bonds.

Polymer chains contain thousands of repeating subunits called monomers.

Polymers also exist in nature, but their chemical bonds break down more easily.

Thermoplastics melt when they get hot, allowing reforming into new shapes.

Thermosets lock into one shape and don't melt when heated.

Chemical additives, like dyes, can sit between the polymer chains.

There are seven kinds of plastic, sorted according to their chemical similarities.

The raw ingredients for plastics are hydrocarbons from coal, gas and oil.

5 FACTS ABOUT COMPANIES MAKING CHANGES

1 Ecostrawz
Ecostrawz make reusable and single-use straws without any plastic. Their glass and metal options last for a good few years, while their bamboo and wheat versions rapidly decompose.

2 KeepCup
The makers of these reusable cups designed them with takeaway coffee in mind. With replaceable parts made from plastic, glass and silicone, they're designed to last for years, not minutes.

3 BioCellection
This California-based start-up focuses on contaminated plastic waste that's too dirty to recycle. They shred the waste, decompose the polymers and turn the plastic into chemicals that can be used for something new.

4 Recycling Technologies
This company uses heat to crack through plastic polymers. Their recycling process breaks up the long strands, turning them back into oil and gas that can then be used again.

5 Vegware
This company sells plant-based disposable packaging to cafes, restaurants and bars. When combined with food waste and sent to industrial recycling facilities Vegware becomes compost in just 12 weeks.

The challenge of recycling

Some items are harder to reycle than others

▲ Easy ▲ Manageable ▲ Difficult ▲ Very difficult

PET
Polyethylene terephthalate
Bottles, food jars, clothing, carpet fibre, some shampoo and mouthwash bottles.
11%
(global plastic waste, 2015)

HDPE
High-density polyethylene
Detergent and bleach bottles, snack boxes, milk jugs, toys, buckets, plant pots and bins.
14%

PVC
Polyvinyl chloride
Credit cards, window and doorframes, gutters, pipes and synthetic leather.
5%

LDPE
Low-density polyethylene
Packaging film, bags, bubble wrap, flexible bottles, wire and cable insulation.
20%

PP
Polypropylene
Bottle tops, drinking straws, lunch boxes, coolers, fabric and carpet fibres, tarps and nappies.
19%

PS
Polystyrene
Plastic-foam cups, egg boxes, meat trays, packing peanuts, coat hangers, yoghurt pots and insulation.
6%

OTHER
Nylon fabrics, baby bottles, compact discs, medical storage containers, car parts and watercooler bottles.
24%

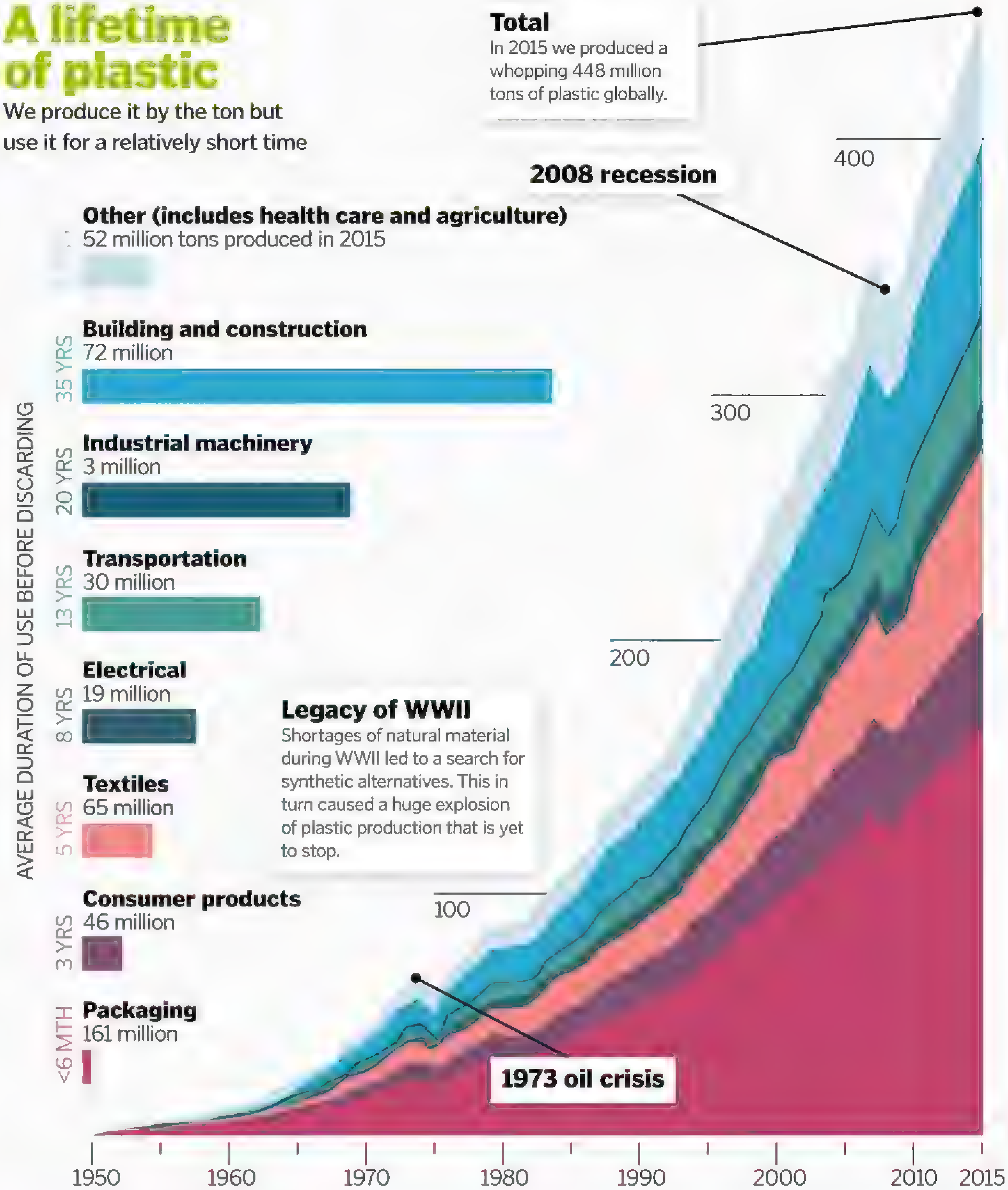
six-pack rings made from barley. Designed to disappear after you use them, they satisfy the craving for single-use solutions without polluting the planet. But knocking plastic off the top spot will take time. Until then, we need to work with what we've got.

In Japan, there are no plastic bans yet. Instead, they focus on waste management, prioritising recycling so that trash never reaches the sea. Non-recyclable plastics pass through incinerators, releasing heat that turns turbines to make electricity. This approach tries to turn our linear model of product design, consumption and waste into a more circular system. The dream would be to close the loop so that all discarded plastics become raw materials for future production. Changes to design and recycling could make products last longer, make them easier to repair and easier to repurpose at the end of their life, and changes to energy recovery methods could help us to get more out of plastics too contaminated for reuse.

This process is already underway. In Europe, a goal set in December 2017 aims to see 55 per cent of plastic packaging recycled by 2030. But there's only so much we can do in our own homes to recycle the goods we buy. To help us to achieve this goal, policy changes could start to make companies responsible for what happens to their products after we've used them. In South Africa, for example, members of the PET Recycling Company pay a levy on the raw materials for plastic production. This money then goes back into redesigning packaging and recycling post-consumer waste. Not only does this help the planet, it also creates jobs, which can be better for economies than banning plastics all together. Back in the UK, the UK Plastics Pact is working with the packaging

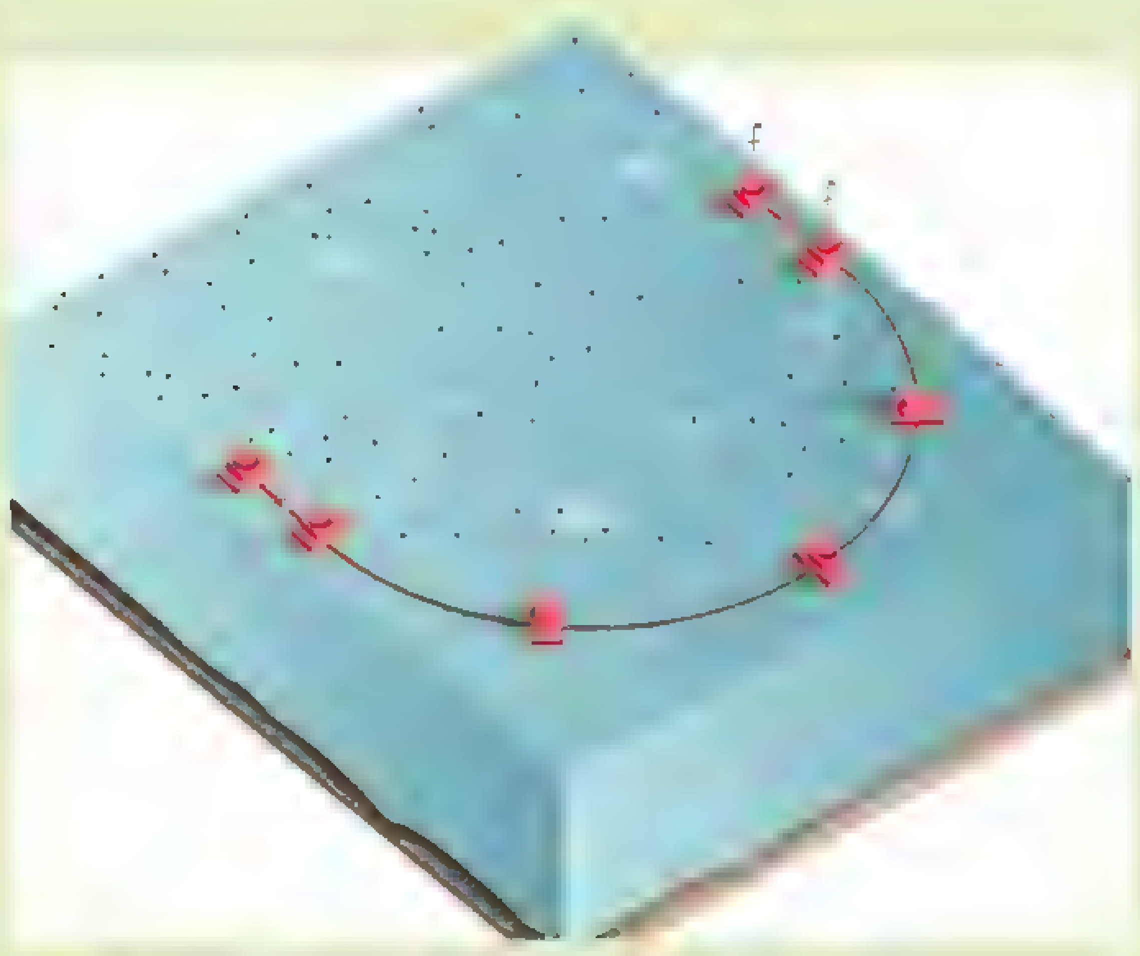
A lifetime of plastic

We produce it by the ton but use it for a relatively short time

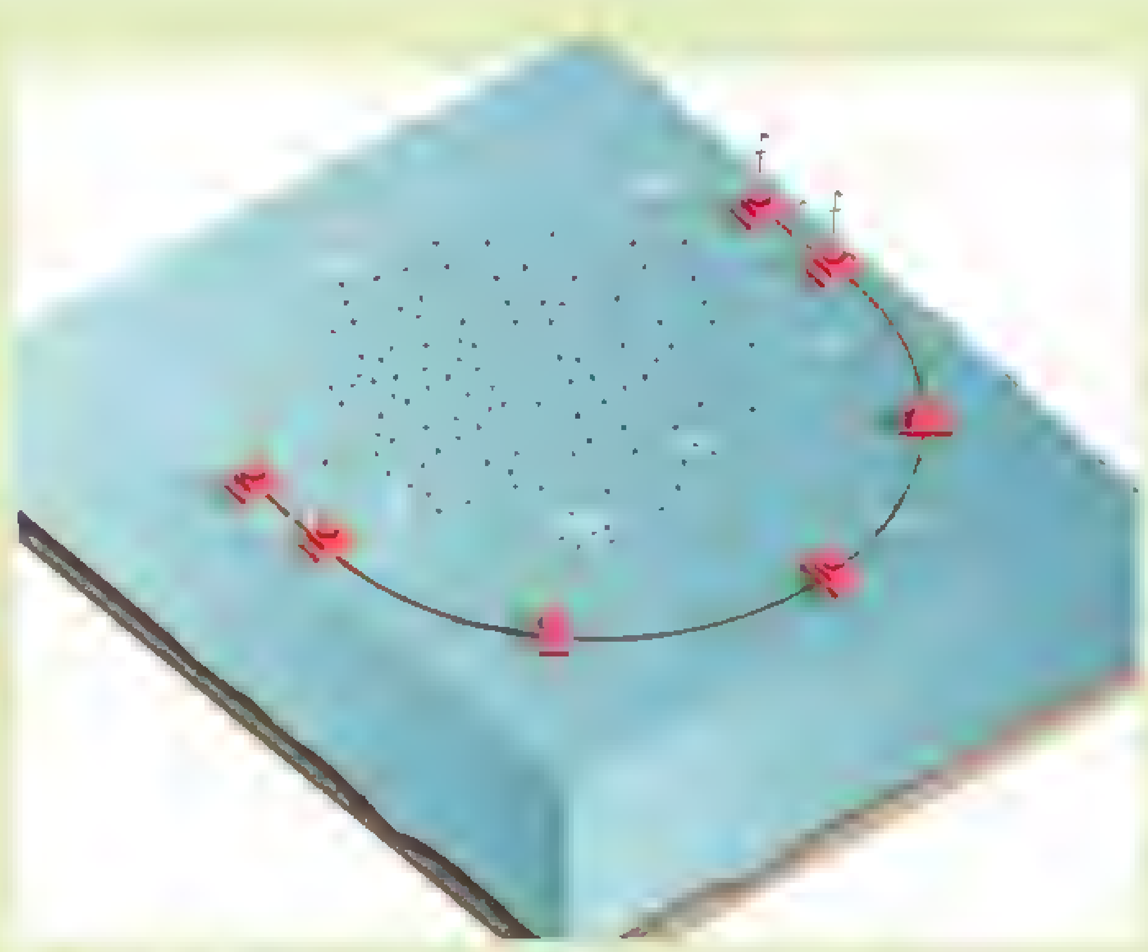


The Ocean Cleanup

1 Chasing plastic
A three-metre skirt dangles from a 600-metre floater. Wind and waves push against the floater, moving it through the water faster than the plastic, which floats in the current.



2 Corralling the plastic
Plastic particles cannot get over the floater or under the skirt. As the wind and waves move the structure through the water the plastic becomes trapped inside.

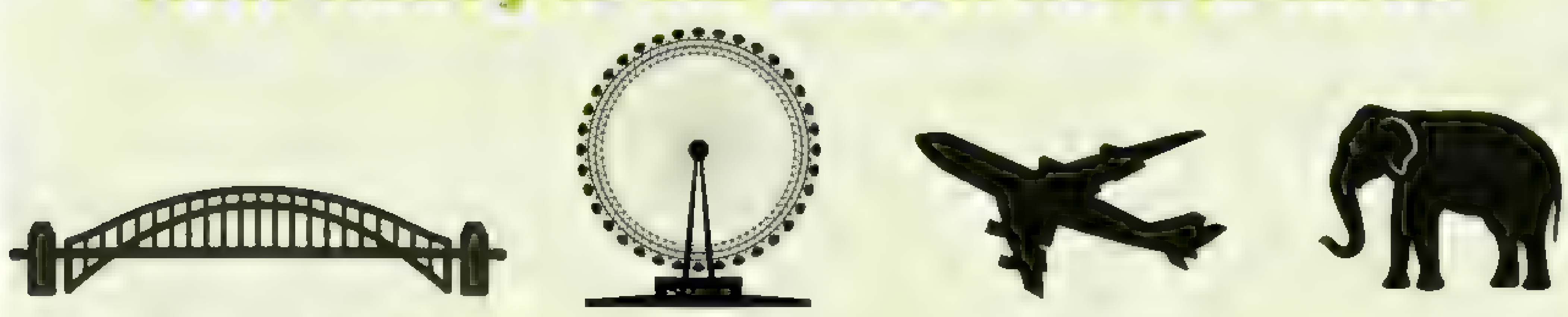


3 Build up
Pressure on the skirt from the current bends the system into a U-shaped trap, preventing plastic from escaping. It moves with the wind, tracking the plastic through the water.

How much plastic do we produce?

1950	2017	2050
2M METRIC TONS	8.3B METRIC TONS	34B PROJECTED METRIC TONS

How heavy is 8.3 billion metric tons?



160,985 x Sydney Harbour Bridge	**4 million x London Eye**	**75 million x Dreamliner**	**1 billion x Elephant**
58,200 metric tons	2,100 metric tons	110 metric tons	7.5 metric tons

Recycling helps to create a circular economy, feeding waste back into production

sector to transition to reusable, recyclable or compostable plastics. They also want to bring plastic recycling up to 70 per cent by 2025.

Scientists are experimenting with biodegradable plastics, like polylactide (PLA). It's made from lactic acid, which comes from corn, and it takes just 12 months to break down. For plastics that we can't recycle, new methods hope to capture more energy from waste by turning them into fuels. A process called gasification heats plastics with air to make a gas that can be burnt. Another, called pyrolysis, heats them without air to make a liquid fuel like oil.

There are still problems to iron out with these new technologies. Burning plastic waste can be hazardous, and to make enough biodegradable plastics to replace the real thing we would need to turn over vast areas of land to corn monocultures. Then there is the fact that even though biodegradable plastics can break down, it doesn't mean that they will. They need to reach temperatures over 50 degrees Celsius, which is achievable inside industrial composters but not when plastics escape into the ocean. But we're moving in the right direction, and we all have a part to play.

We as individuals can choose alternatives to plastics and put pressure on governments and brands to make bigger changes. If we focus on reduction, reuse and recycling, we could close the loop in the plastic economy and stop this incredible material leaking out into the sea.

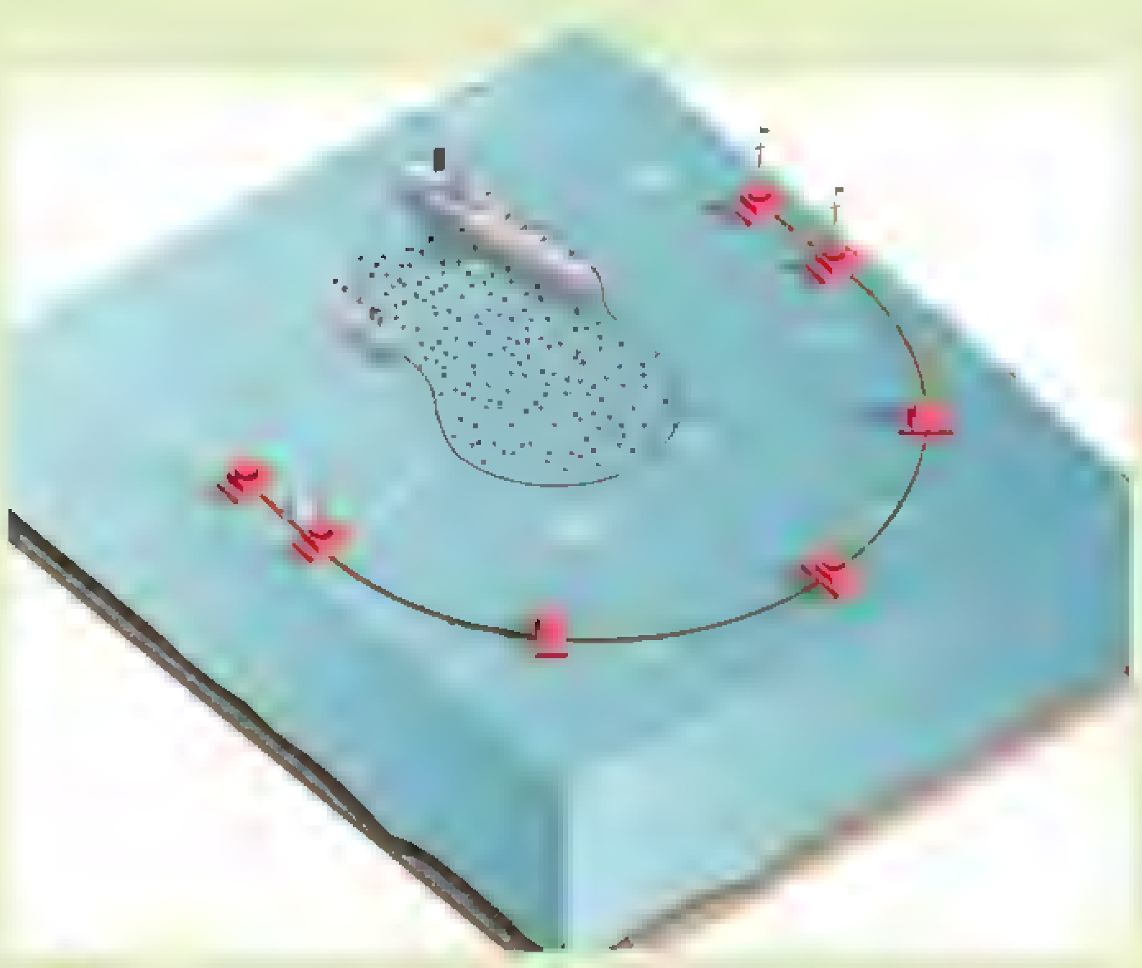
Why won't plastic biodegrade?

Microbes quickly get to work on organic waste, like paper and vegetable peelings, but they can't get to grips with plastic. This might seem odd, as we make plastic from oil, which comes from the remains of ancient plants and animals, but it's all down to the way plastic is made.

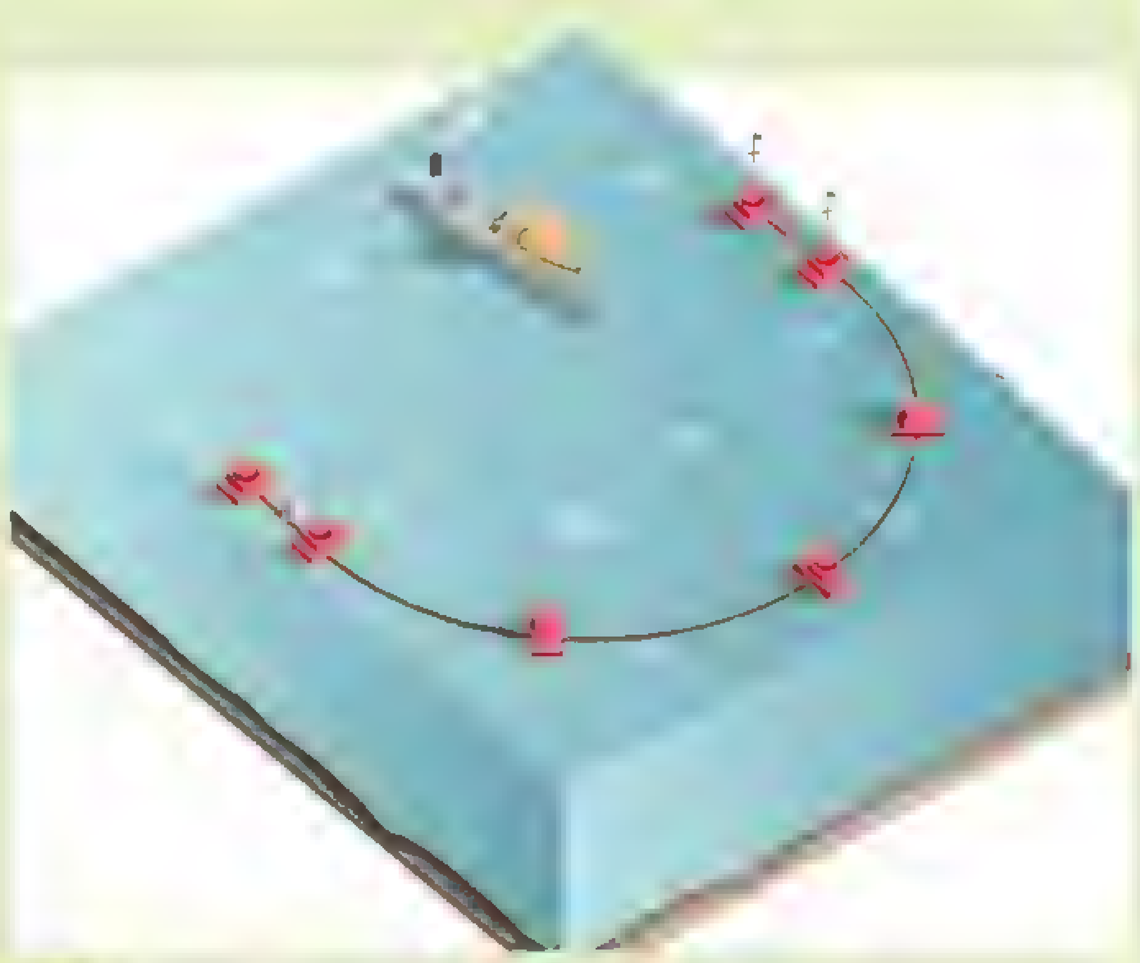
Natural polymers use chemical links called peptide bonds, while plastic polymers contain carbon-carbon bonds. These bonds are much stronger, and that's both a gift and a curse. Most of the enzymes living things use to break organic molecules down can't manage to break these links. This helps to make plastics so durable, but it also makes them hard to get rid of.

There are only a handful of organisms, including some fungi and bacteria, capable of breaking them down. Scientists are still working out how best to use them. Ironically, if more organisms learn this trick, it could put the durability of vital plastic structures under threat.

[illegible] globally every year

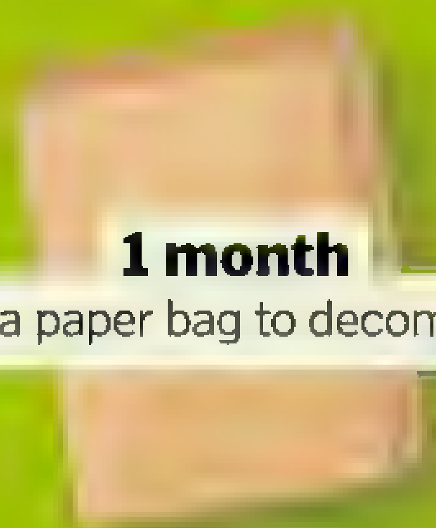


4 Clean up
The system sends signals to satellites overhead, keeping operators updated about its status. As plastic starts to build up, support vessels come in to gather the waste.



5 Recycling
The collected plastic returns to shore for proper disposal. Meanwhile, the system continues to move through the water collecting even more waste.

How long does waste take to break down?



1 month
For a paper bag to decompose

2 months
To get rid of a cardboard box

1 million years
For an aluminium can to break apart

2 years
To compost an orange peel

12 years
For a cigarette butt to disintegrate

20 years
Until a plastic bag breaks apart

450 years
For a plastic bottle to fall to bits

WHAT CA

SAY NO TO SINGLE-USE CUTLERY

We only use plastic cutlery for a few minutes before we throw it away, so minimise your plastic footprint by refusing disposable knives, forks and straws. Pop a normal fork in your bag for lunch on the go and invest in a washable metal straw if you can't go without. If you find yourself caught out, look for outlets offering biodegradable or edible cutlery.

CARRY A REUSABLE CUP AND WATER BOTTLE WITH YOU

[illegible]

TRY ZERO-WASTE SHOPPING

[illegible]

DID YOU KNOW? *Recycled plastic can go on to become bottles, benches, bins, jackets, insulation and even car batteries*

AN YOU DO?

INVEST IN REUSABLE BAGS AND BOXES

Ditch cling-film, freezer bags and foam takeaway packets and invest in a set of reusable bags and boxes for your lunch and leftovers. Hard, recyclable plastic boxes last much longer than their disposable counterparts and can be stored in the fridge or freezer and put in a microwave. Or, if you'd prefer to be completely plastic free, you could opt for glass, metal or dishwasher-safe silicone.

SWAP LIQUIDS FOR BARS AND POWDERS

[illegible]

SWITCH TO REUSABLE NAPPIES

[illegible]

SPACE

DESIGNING THE ULTIMATE SPACESUIT

Discover the fashionable future of spacesuits and how they keep astronauts alive

Words by **Scott Dutfield**

Since its debut more than 50 years ago, the spacesuit has evolved alongside our space exploration ambitions. More than just functional fashion, the concept of a spacesuit is essentially to act as a personal spaceship for a human passenger.

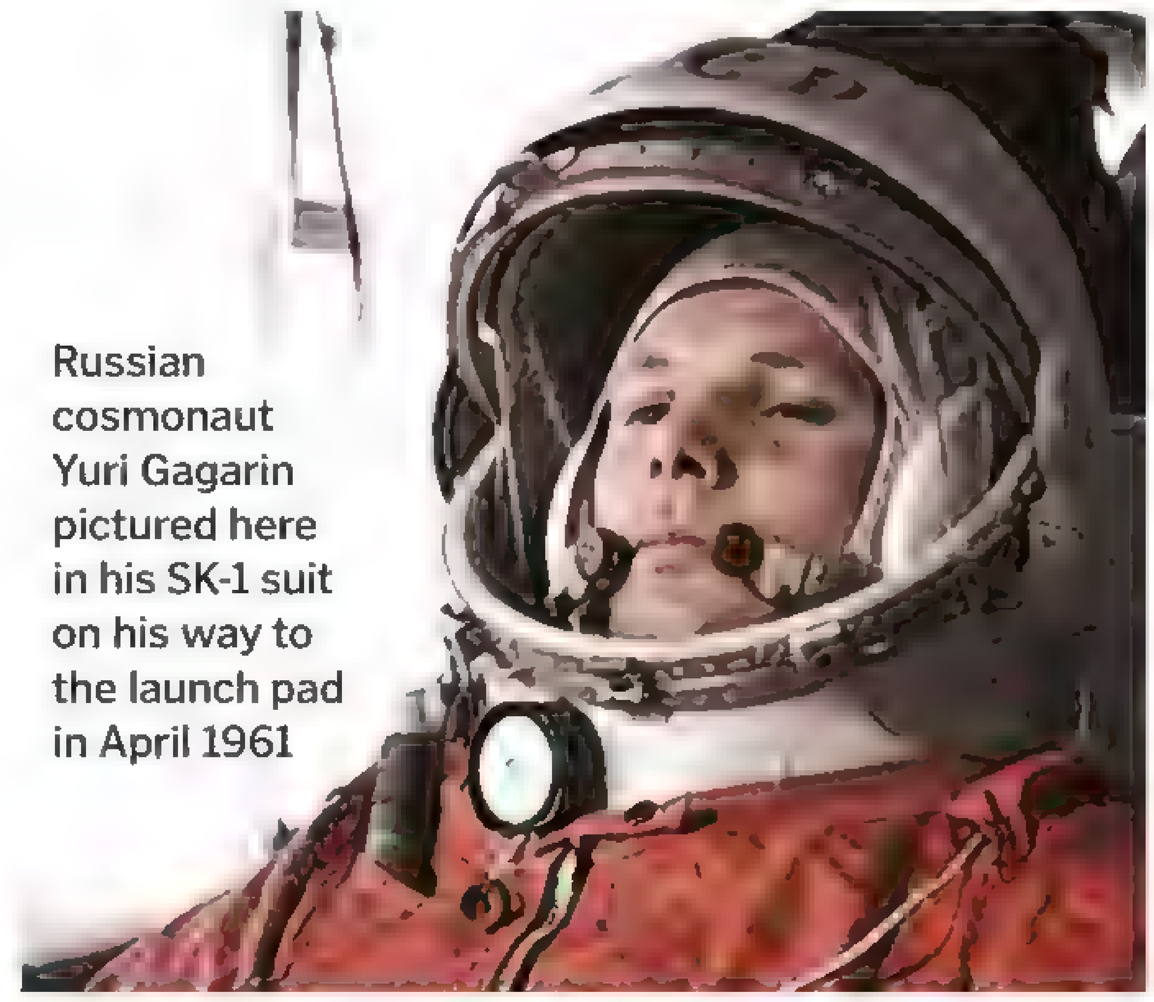
Different suits are worn during different stages of a mission. Intravehicular activity (IVA) suits, like the Russian Sokol, are worn during launch and re-entry to protect astronauts in the event of an emergency, such as sudden cabin depressurisation during launch. NASA used a similar design – the Advanced Crew Escape Suit (ACES), also known as the 'pumpkin suit' due to its bright orange fabric – for many of its Space Shuttle missions.

Boeing have been developing a new IVA suit for their future Crew Space Transportation (CST)-100 Starliner spacecraft, designed in collaboration with NASA to ferry astronauts to the ISS and other low-Earth orbit destinations. The striking blue Boeing Ascent/Entry Suit (AES) is an improved version of the ACES, offering greater mobility and reduced weight. One of the most notable features of the suit is an incorporated headgear. Rather than the typical detachable helmet, the Starliner's resembles more of a pressurised hood with an airtight zip.

Boeing aren't the only private company entering the spacesuit race. SpaceX is developing a suit for the first manned mission of their Crew Dragon capsule, due to take place in the next few years. SpaceX CEO Elon Musk has maintained a sense of mystery around the suit's technology and finer details, but judging by a picture released in 2017 the suit appears to have improved mobility and a more streamlined design compared to current IVAs.

Alan Shepard, pictured here in his Mercury pressure suit, was the first American in space in May 1961

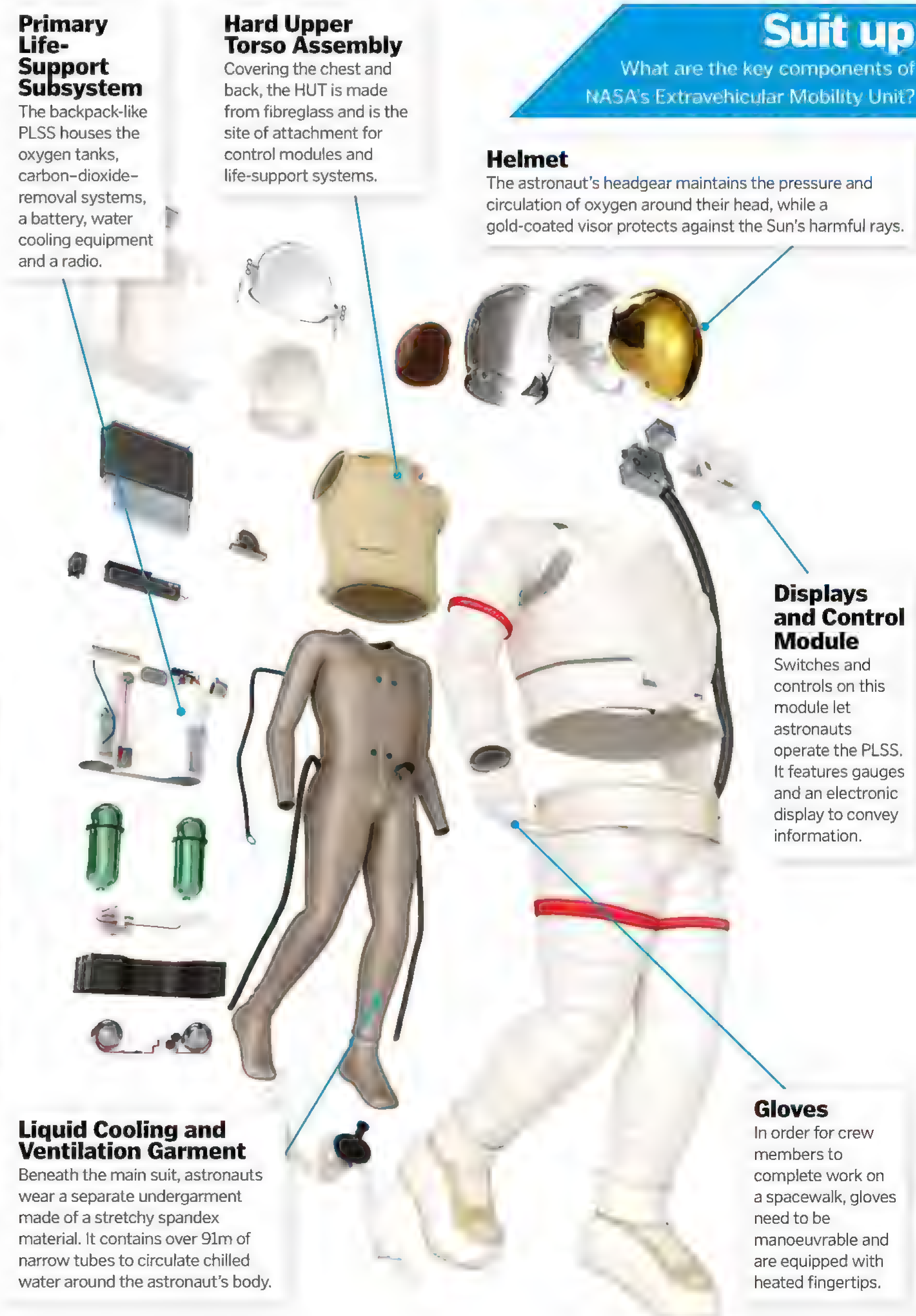
The second all-important spacesuit for an astronaut venturing outside their vessel is the extravehicular activity (EVA) suit, which provides vital protection against the extremes of outer space. The first spacewalk was performed on 18 March 1965 by cosmonaut Alexei Leonov, who wore the Berkut suit – a combined IVA and EVA suit. Leonov was uniquely qualified to offer feedback on the suit when he returned, helping to improve designs for future missions. In June of the same year Ed White became the first American to perform a spacewalk in the Gemini G4C suit. It was connected to a long tether to keep White attached to the spacecraft. He also had a



Russian cosmonaut Yuri Gagarin pictured here in his SK-1 suit on his way to the launch pad in April 1961

Suit up

What are the key components of NASA's Extravehicular Mobility Unit?



Hand-Held Maneuvering Unit (HHMU), an oxygen jet gun that he could use to propel himself and move around.

During his spacewalk, White was connected to the life-support system of the Gemini spacecraft via a 7.6-metre-long 'umbilical cord'. However, this setup limited the distance an astronaut could travel during an EVA. Subsequent spacesuit designs (such as the Apollo A7L suits used in the lunar landings) included a backpack-style life-support system to make the suits more portable. These new and improved suits provided essential oxygen, carbon dioxide removal and internal temperature control while also giving astronauts more freedom of movement. These life-sustaining accessories are just one of the many aspects that spacesuit designers must consider when creating the perfect suit.

The colour of an EVA suit is also more important that you might think. Due to the absence of an atmosphere, in the direct path of sunlight temperatures can reach 120 degrees Celsius or more, whereas in the shade it can drop to below -150. Protecting astronauts from frying or freezing is where the colour comes in. Spacesuits are white because this colour is the most effective at reflecting heat.

Another important purpose of an EVA suit is to protect the astronaut inside from the lack of pressure in open space. The standard for any suit is to recreate one-third of Earth's atmospheric pressure, which is enough to maintain bodily functions, such as the inflation of lungs and blood flow. This is typically achieved by pumping gas into the suit to generate an artificial atmosphere, a concept that is also applied to suits designed for other extreme-pressure environments such as at high altitudes or in the depths of the ocean.

"New and improved spacesuits gave astronauts more freedom of movement"


Cosmonaut Alexander Skvortsov conducting a spacewalk in the Orlan suit in 2014

Through space and time

How suits have evolved since the dawn of the space age

Mercury suits

Years active: 1961–63

Originally designed for the US Navy, the aluminium-coated Mark-IV pressure suit offered protection against unpressurised conditions during manned Project Mercury missions. Instead of a backpack of oxygen, the gas was fed into the suit via an 'umbilical cord' at the waist.

SK-1

Years active: 1961–63

The very first spacesuit was the SK-1 model worn by Yuri Gagarin during his historic Vostok 1 flight that orbited the Earth. The bright orange suit was pressurised and contained auxiliary life-support systems.

Gemini suits

Years active: 1965–66

Used in the first US spacewalk by Ed White, the Gemini suit was based on the pressure suit used for the hypersonic X-15 rocket plane. The layers that made up the suit increased during the Gemini programme to facilitate different missions.

Apollo suits

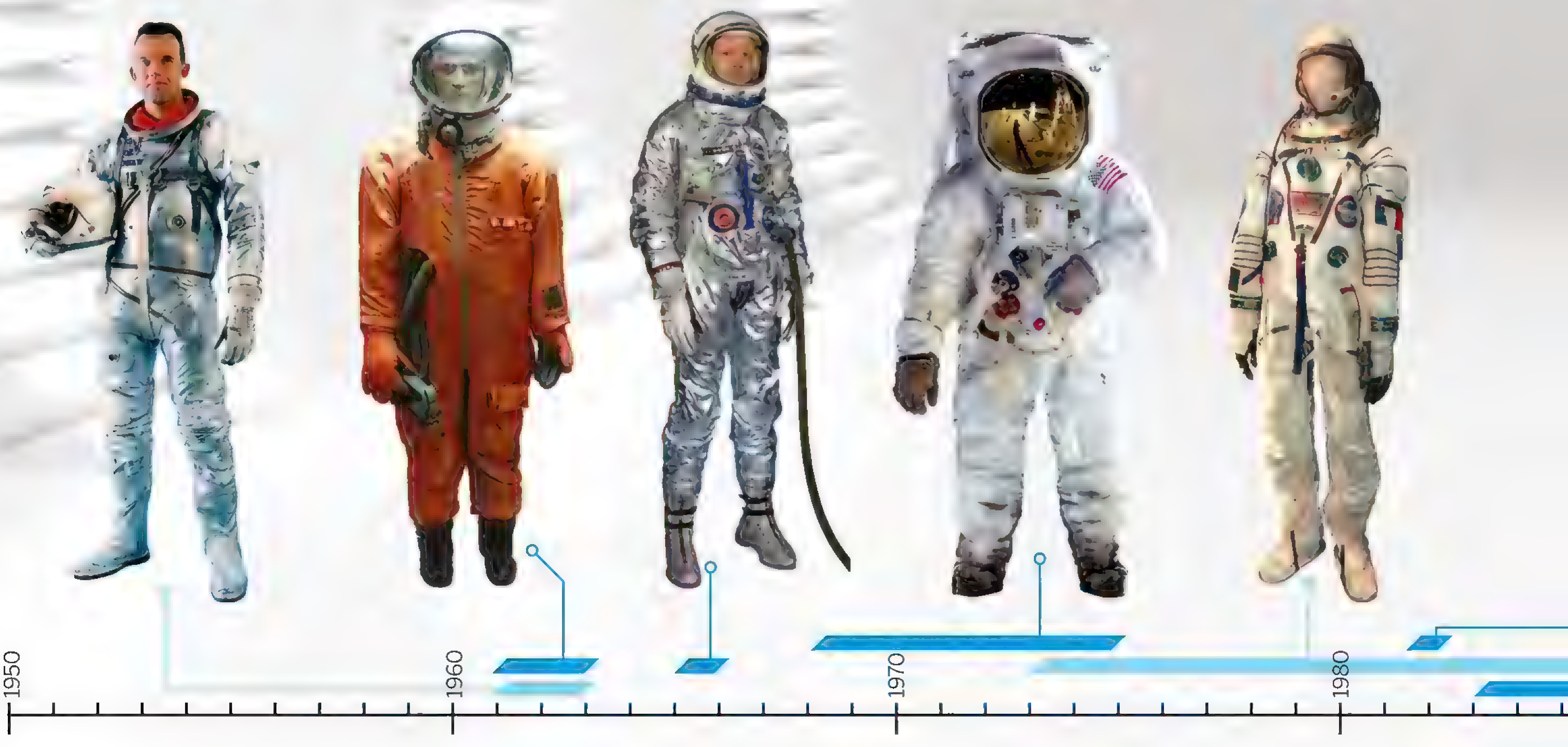
Years active: 1968–75

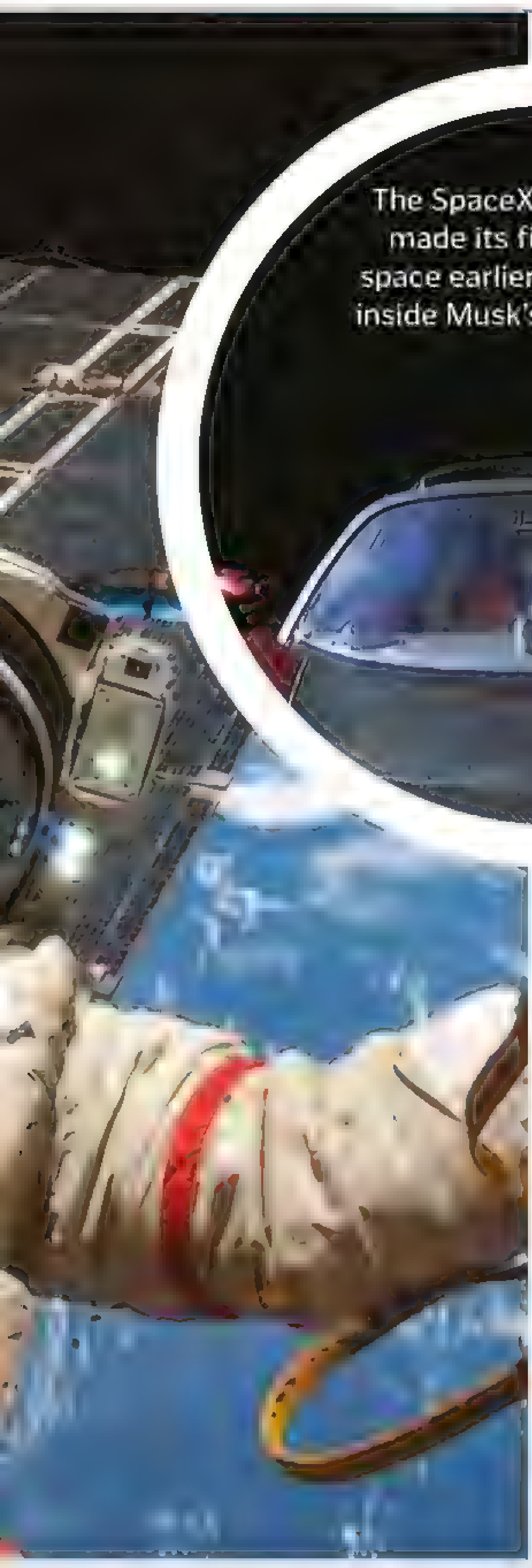
The Apollo A7L suit was worn during moonwalks and was the first suit with an independent life-support system. It also featured an outer Thermal Micrometeoroid Garment layer to shield against lunar dust.

Sokol-KV2

Years active: 1973–present

The Russian-made Sokol suit is tailored to fit each astronaut. The suit can be connected to the Soyuz's life-support system to provide two hours of oxygen and carbon dioxide removal in the event of emergency decompression.





The SpaceX suit prototype made its first journey to space earlier this year riding inside Musk's Tesla Roadster

NASA aims to land humans on Mars during the 2030s, a feat that will require a new generation of spacesuits

Shuttle Ejection Escape Suit

Years active: 1981–82

When early Space Shuttles had ejection seats, this suit was designed to protect the wearer up to altitudes of 24 kilometres. Instead of a life-support system, it relied on astronauts falling to lower altitudes after ejecting. Thankfully, it was never needed.

Launch Entry Suit

Years active: 1988–94

Used on STS-26 to STS-65 missions, the LES could provide 30 minutes of air supply in case of an emergency, plus a survival backpack with a parachute, raft and survival equipment in case astronauts landed in the wilderness.

Extravehicular Mobility Unit

Years active: 1983–present

NASA's current EVA suit is effectively a self-contained spacecraft. It features a hard torso shell and an internal cooling suit, and it can typically provide life-support for 8.5 hours. The Russian Orlan suit (pictured above-left) is also used for EVAs on the ISS.

Advanced Crew Escape Suit

Years active: 1994–2011, possible future use

The ACES was born from the US Air Force's high-altitude pressure suits. The bright orange 'pumpkin' suit made Space Shuttle crew members easy to spot if they bailed out in landings at sea. NASA are currently modifying the suit for future Orion missions.

Gas-pressurised suits are currently the norm for space exploration, but that's not to say the design can't be improved. The BioSuit, developed by MIT professor Dava Newman, is a form-fitting design that does away with the need for pressurising gases altogether. The biggest downfall for many EVA spacesuits is that they restrict astronauts' movements. However, Newman's BioSuit acts like a second skin, shrink-wrapping around the body by activating the nickel-titanium shape-memory alloys woven into its fabric. As the coils of the alloys are tightened, the suit generates the pressure needed to keep an astronaut alive via mechanical pressure applied directly to the skin rather than atmospheric pressure. Should the suit become suitable for planetary exploration, this would enable crew members to move around with much more freedom.

The BioSuit is just one of many future suits currently in development. NASA's aim to send humans to the Red Planet during the 2030s has inspired a new generation of spacesuits. In 2014, NASA revealed their designs for their futuristic Z-2, which is being developed as a durable planetary EVA suit – a successor to the current EMU and Z-1 prototype. Some of the new additions include electroluminescent wiring and improved walking boots. The latter have not been required since astronauts last visited the lunar surface in 1972.

Whether it's the sleek style of the SpaceX design, the BioSuit, or the futuristic fashion of the Z-2, whichever suit future astronauts wear as they step onto the surface of Mars will represent another giant technological leap for humankind.


In 1984, Bruce McCandless became the first person to fly untethered during a spacewalk, using a jetpack to manoeuvre instead


The BioSuit design uses physical counter-pressure to keep astronauts alive

Spacesuits of the future

The next-gen designs in development right now

"Walking boots have not been required since we last visited the Moon"

NASA Z-2 prototype

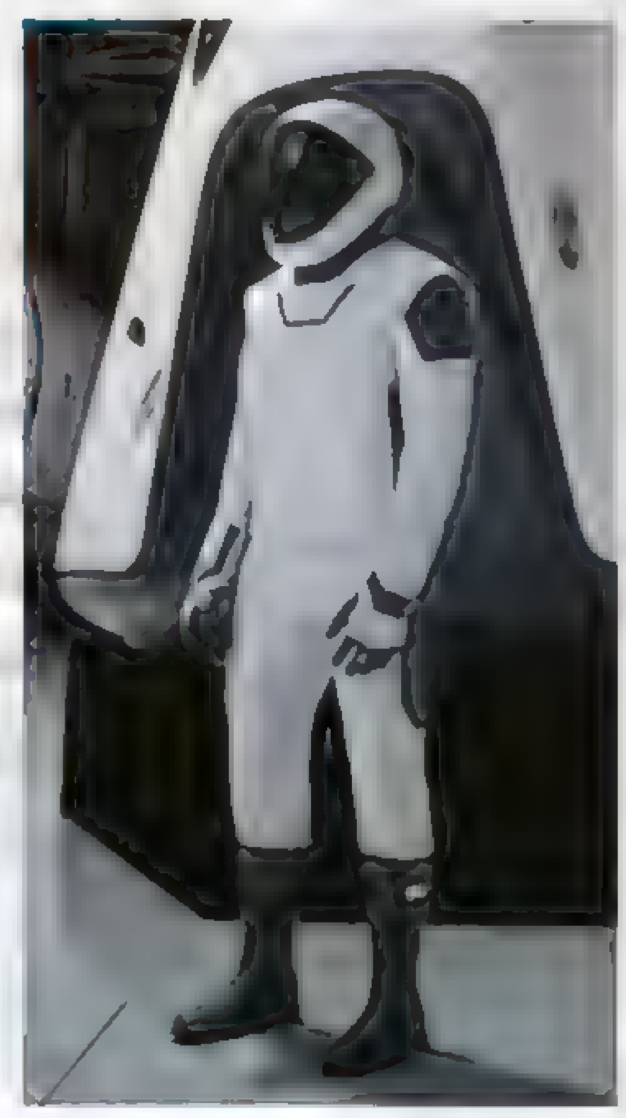
Year revealed: 2014
Scheduled first use: Prototype only

Similar in design to the current EMU, the Z-2 is an upgraded planetary spacesuit concept intended to offer improved mobility with adjustable shoulder and waist sizes. Astronauts will enter the suit through a new style back hatch.

Boeing Starliner suit

Year revealed: 2017
Scheduled first use: Crewed test flights in 2018-19

The Starliner's launch and re-entry IVA suit is around five kilograms lighter than the current ACES. Improvements also include touchscreen-friendly gloves and a zip-fastened helmet.



SpaceX suit

Year revealed: 2017
Scheduled first use: Crewed test flight in late 2018

Not much information has been released about the SpaceX suit. The futuristic IVA has been designed to be sleek in form and function, with the potential to offer crew members increased mobility and dexterity.

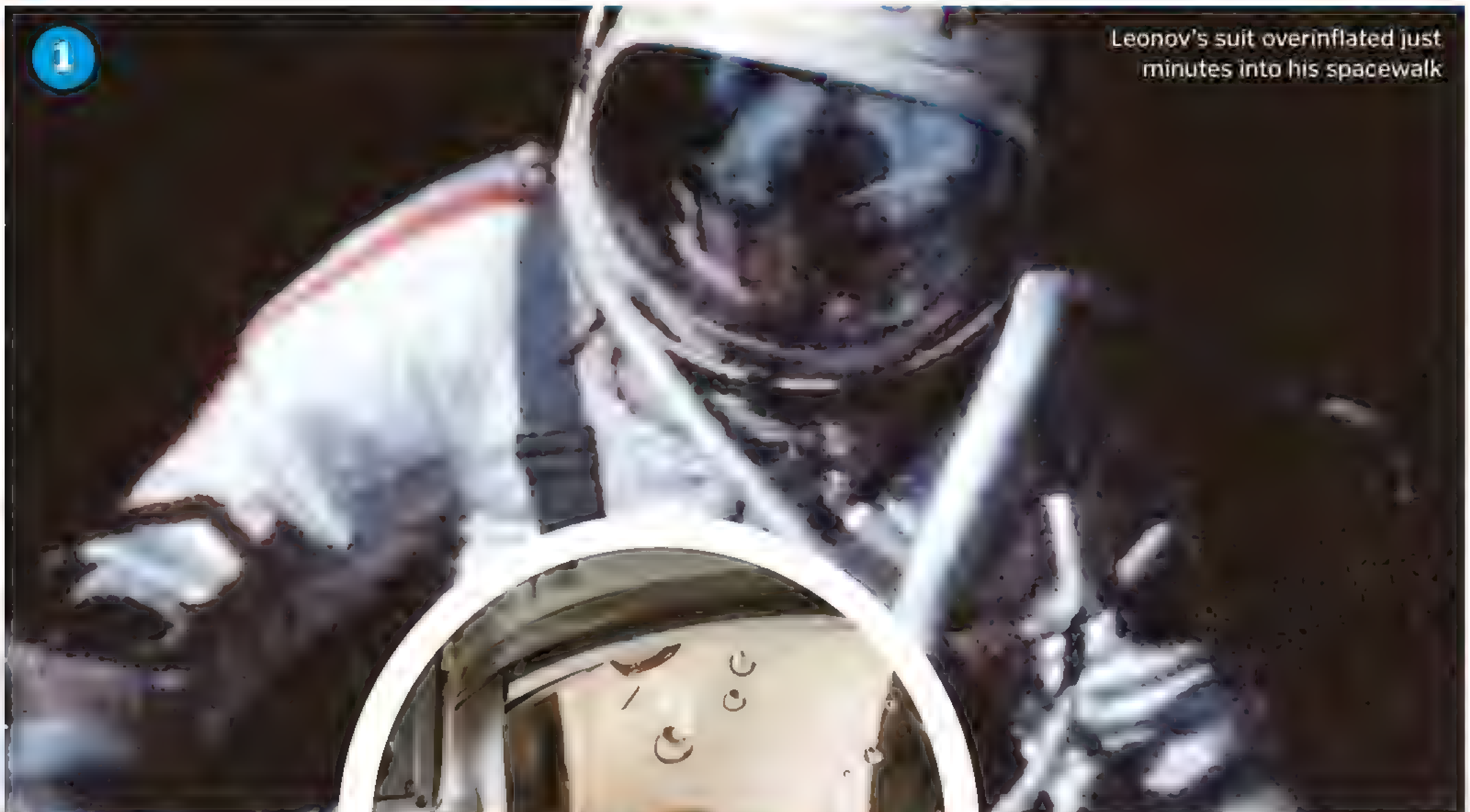
Spider Flyer-Walker suit

Year revealed: 2017
Scheduled first use: Prototype only

This innovative concept from Lockheed Martin is an eight-legged suit equipped with small thrusters, enabling future Mars astronauts to collect samples and work on the Red Planet's surface while anchored to the ground.

"HOUSTON. WE'VE HAD A PROBLEM..."

What happens when spacesuits go wrong?



Leonov's suit overinflated just minutes into his spacewalk

Left: NASA performed tests on empty helmets to find out what caused the fault during Parmitano's 2013 spacewalk

It is estimated that around 1-1.5 litres of water filled Parmitano's helmet during the incident

Only once Apt re-entered the spacecraft did he notice something had gone wrong

Hadfield was blinded by his own tears on a spacewalk that could have ended in disaster

1 Alexei Leonov *1965*

After leaving the Voskhod 2 spacecraft to perform the first ever spacewalk, cosmonaut Alexei Leonov's suit began to swell due to the pressure difference. Within just 12 minutes of EVA he became too big to fit back into the spacecraft so released some of the oxygen filling his suit through a valve, depressurising it enough to re-enter the spacecraft.

2 Luca Parmitano *2013*

While on a routine EVA, Parmitano was surprised to feel water on the back of his neck. A blockage in his spacesuit's water separator led to a leak that started to fill his helmet and could have drowned him. Luckily, Parmitano was able to blindly make his way back to the safety of the airlock by memory.

3 Jerome 'Jay' Apt *1991*

Returning from his second spacewalk, Jay Apt removed his gloves only to find that a metal bar in his glove had somehow become loose and punctured a tiny hole in his suit – along with his hand – while out in space.

4 Chris Hadfield *2001*

On Hadfield's first spacewalk, anti-fogging solution irritated his left eye and caused it to tear up. The ball of tears then hit his right eye, leaving him temporarily blinded. Luckily, his tears eventually flushed the irritant out. Vision restored, he was able to complete the spacewalk.

Creepy cosmos

The universe is a weird and wonderful place, but some of the strange new worlds we've discovered are far from welcoming…

In October 2014, our own Sun's active regions gave it the appearance of a jack-o'-lantern

Eternal darkness

Planet: TrES-2b
Discovered: 2006
Distance from Earth: 750 lightyears

This alien gas giant reflects less than one per cent of the sunlight that falls on it, making it blacker than coal and the darkest known exoplanet. It orbits just 4.8 million kilometres from its parent star, heating its atmosphere to over 980 degrees Celsius – too hot for reflective clouds like those on Jupiter to exist. Instead, its atmosphere consists of light-absorbing chemicals like titanium oxide gas and vaporised sodium and potassium.

Deadly rain

Planet: HD 189733 b
Discovered: 2005
Distance from Earth: 63 lightyears

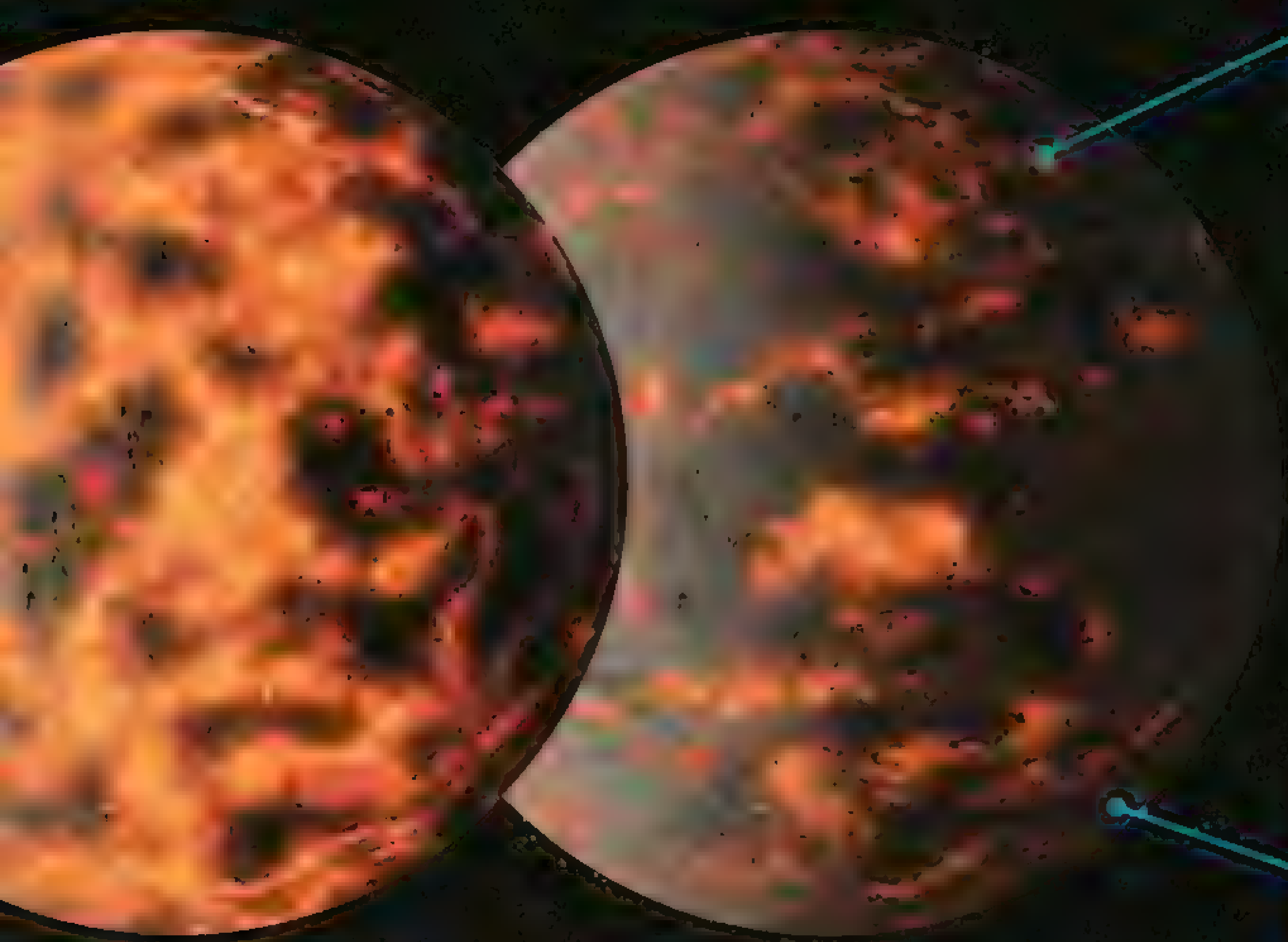
If the barefoot scene from *Die Hard* makes you wince, you wouldn't like life on this exoplanet. It rains shards of glass in over 7,000-kilometre-per-hour winds. This world may be blue like ours, but it's nothing like Earth. Its colour comes from silicate particles condensing into glass in the superheated atmosphere. These glass raindrops scatter more blue light than red, resulting in swirls of cobalt clouds.

Doomed planet

Planet: Wasp-12b
Discovered: 2008
Distance from Earth: 1,400 lightyears

Similar to TrES-2b, Wasp-12b is another hot, Jupiter-like world that reflects very little light. If this wasn't bad enough, the planet itself is slowly being 'eaten' as its atmosphere is escaping into the grasp of its parent star. It's estimated that Wasp-12b will be fully consumed within the next 10 million years.

> "The exoplanet KELT-9b is classed as an 'ultrahot Jupiter' – it reaches temperatures of over 4,300°C"



Two-faced super-Earth

Planet: 55 Cancri e
Discovered: 2004
Distance from Earth: 40 lightyears

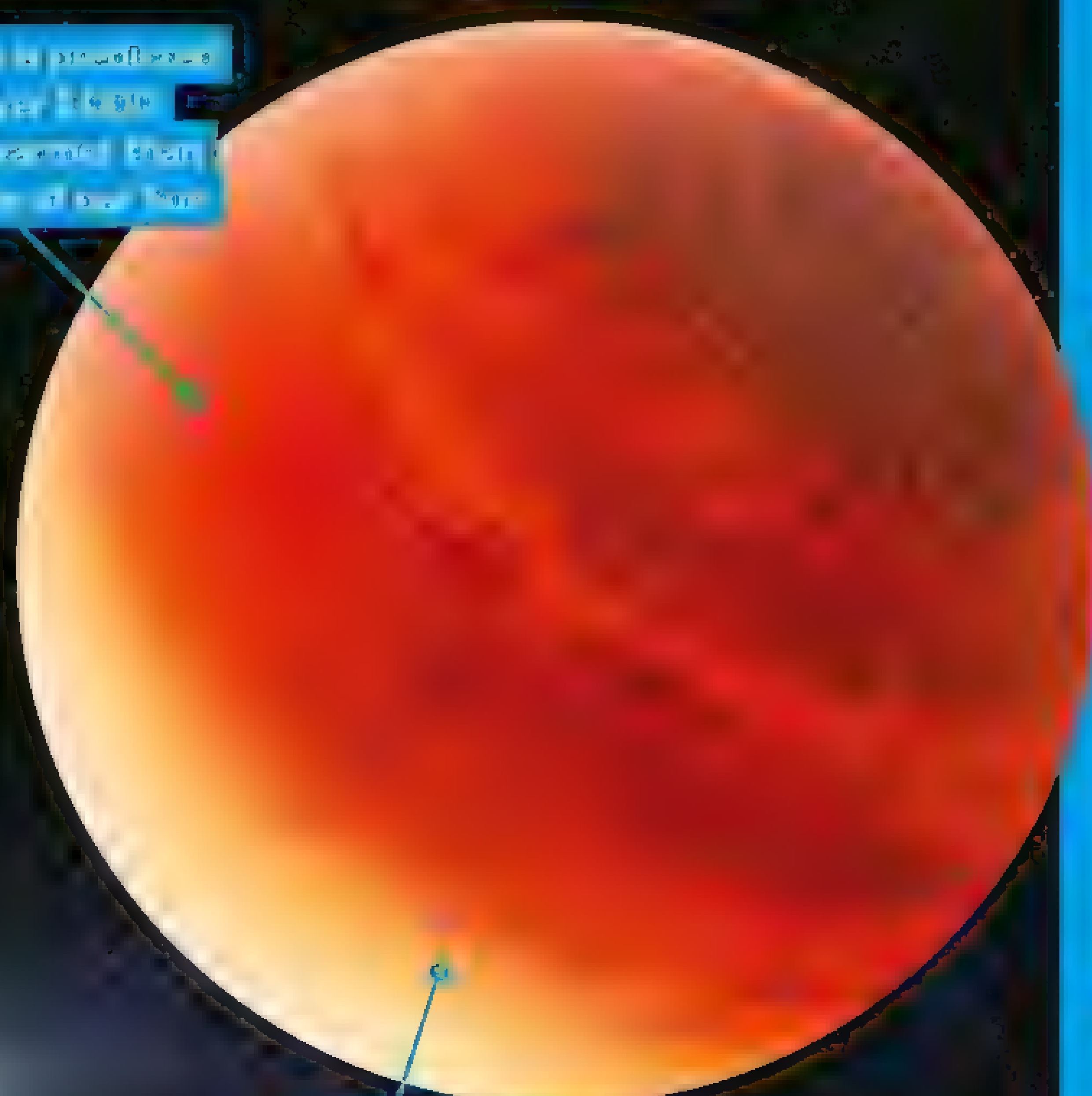
This weird world is tidally locked to its star, meaning one side is in permanent daylight while the other experiences a never-ending night. The day side averages temperatures of over 2,300 degrees Celsius, while the cooler night side is 'just' around 1,300 degrees. Observations from the Spitzer telescope originally indicated that this may be a lava world covered in moulten rock that flowed on the light side and solidified on the dark side. However, more recent analysis suggests it probably has a thick atmosphere, which may or may not be hiding lava lakes below.

[illegible]

Iron skies

Planet: KELT-9b
Discovered: 2017
Distance from Earth: 615 lightyears

KELT-9b holds the record for being the hottest known gas giant discovered so far. It's so hot in fact that the term 'hot Jupiter' wouldn't do it justice – instead, it is classed as an 'ultrahot Jupiter'. It reaches temperatures of over 4,300 degrees Celsius as it orbits its extremely hot, young blue star. Analysis of KELT-9b's spectral data revealed that its superheated atmosphere contains iron and titanium atoms. While these elements are common, they are usually present within other molecules. On KELT-9b it's too hot for clouds to condense, so these metals can exist alone.



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Burned alive

Planet: Kepler-70b
Discovered: 2011
Distance from Earth: 4,200 lightyears

It is thought that this rocky world used to be a gas giant like Jupiter until it was engulfed by its star. Kepler-70 expanded into a red giant, swallowing the surrounding planets and spitting them back out again as it shrank to its current sub-dwarf form. The planets survived, but taking a trip into a star did not leave them unscathed. Kepler-70b's rocky form is all that remains after its gaseous atmosphere was vaporised. It's also the hottest exoplanet ever discovered, with temperatures estimated at around 6,800 degrees Celsius.

[illegible]

Radioactive graveyard

Planet: Draugr, Poltergeist and Phobetor (PSR 1257+12 b, c and d)
Discovered: 1992-1994
Distance from Earth: 2,300 lightyears

PSR 1257+12 b, c and d was the first confirmed exoplanet system to be discovered, but any hopes of them being habitable were well and truly dashed. They are in orbit around a pulsar – the collapsed core of a star that forms after a supernova. The dramatic stellar explosion would have stripped the planets of any atmosphere or life that may have existed upon them, and the remnant 'corpse star' pulsar now bathes them in intense, deadly radiation.

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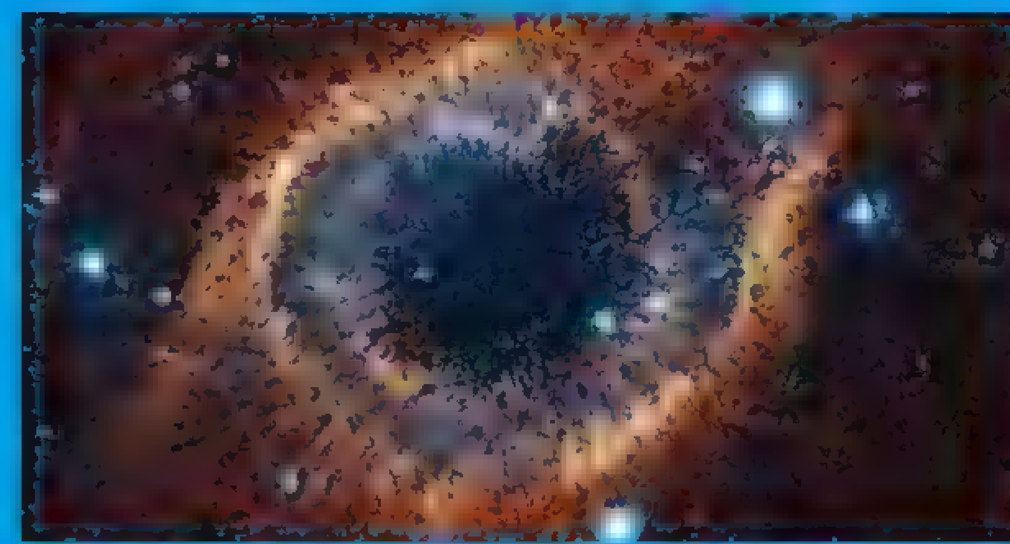
Five phenomenally freaky nebulas



The Eye of Sauron (NGC 7293)

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Galactic Ghoul (DR 6)

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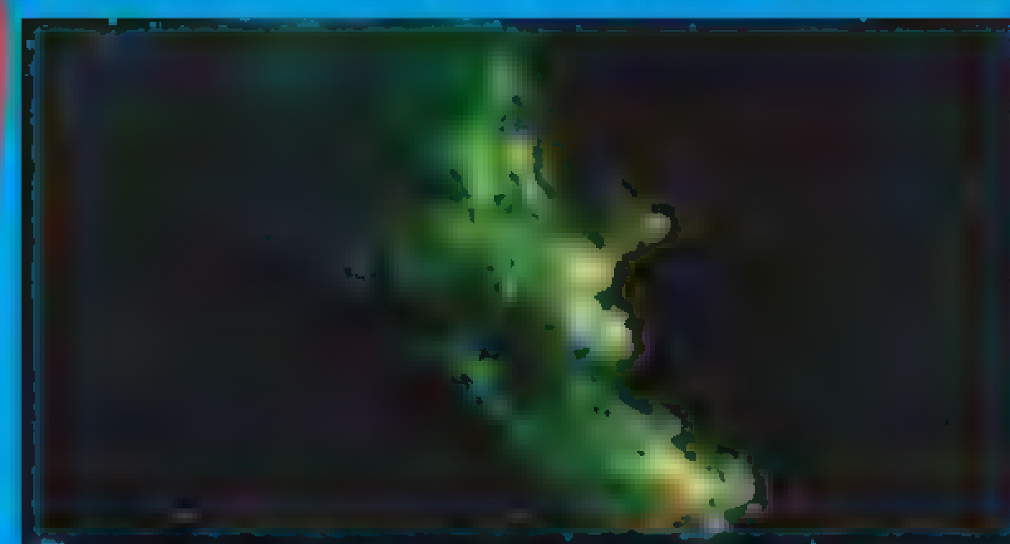

Witch Head Nebula (IC 2118)

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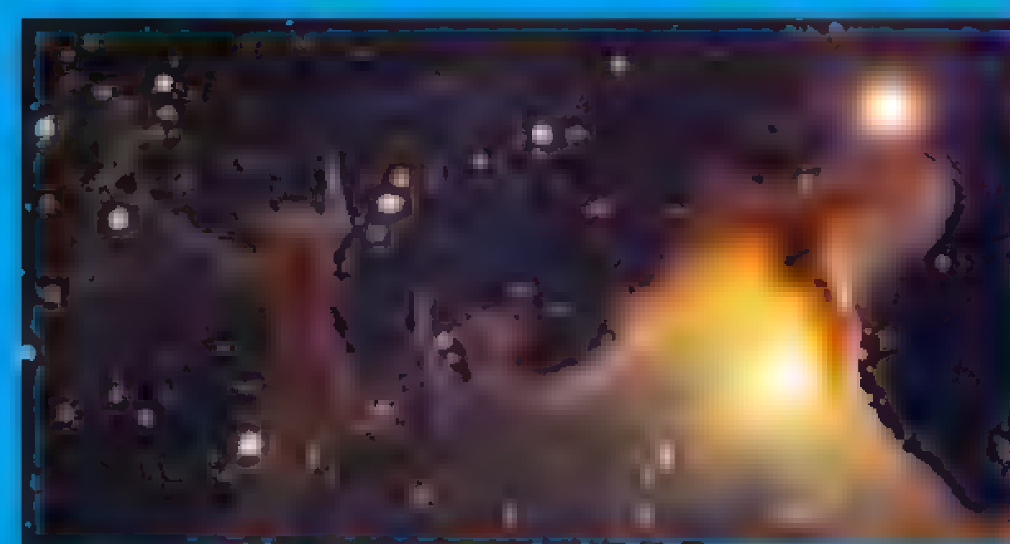


Ghost Nebula (Sh2-136)

The billowing clouds of this nebula look strangely like small human-like figures fleeing in terror from a foreboding phantom.

Ghost Head Nebula (NGC 2080)

[illegible]

The make-up of the Moon

The Moon's violent history has led to its rather colourful present

Regardless of what Wallace and Gromit may have told their viewers, the Moon is not made of cheese. The fifth largest moon in the Solar System, and our nearest neighbour, is made primarily of rock. Almost similar to Earth, the Moon is also composed of a core, mantle and crust, but its geological activity is extinct now.

The centre of the Moon is an iron-rich core accounting for roughly 20 per cent of its radius. There is a partially molten region surrounding the iron core and then a mantle that stretches between the molten core layer to the crust of the Moon, most likely composed of minerals like olivine and pyroxene.

The crust of the Moon has a thickness ranging from 70 to 150 kilometres, and its composition has been observed to contain oxygen, silicon, magnesium, iron, calcium and aluminium. It also contains relatively small amounts of titanium, uranium, thorium, potassium and hydrogen. All of these elements make up the stunning surface of the Moon that everyone can see from Earth, consisting of dark Maria (Latin for 'seas') that were once impact basins filled with lava. The volcanoes spread all over the lunar surface were once active, but now they all lie dormant, having not had an eruption for millions of years. The only refreshment the surface receives is when an asteroid hits it, causing the many impact craters visible from Earth.

NASA's Galileo spacecraft imaged the Moon's northern hemisphere using its Solid-State Imaging (SSI) instrument while on its voyage to Jupiter, creating a spectacular image. The SSI was capable of capturing many different images in varying wavelengths ranging from visible to near-infrared light. The different wavelengths correspond to a different colour and composition, meaning the scientists behind the mission could visually distinguish the different compositions on the lunar surface.

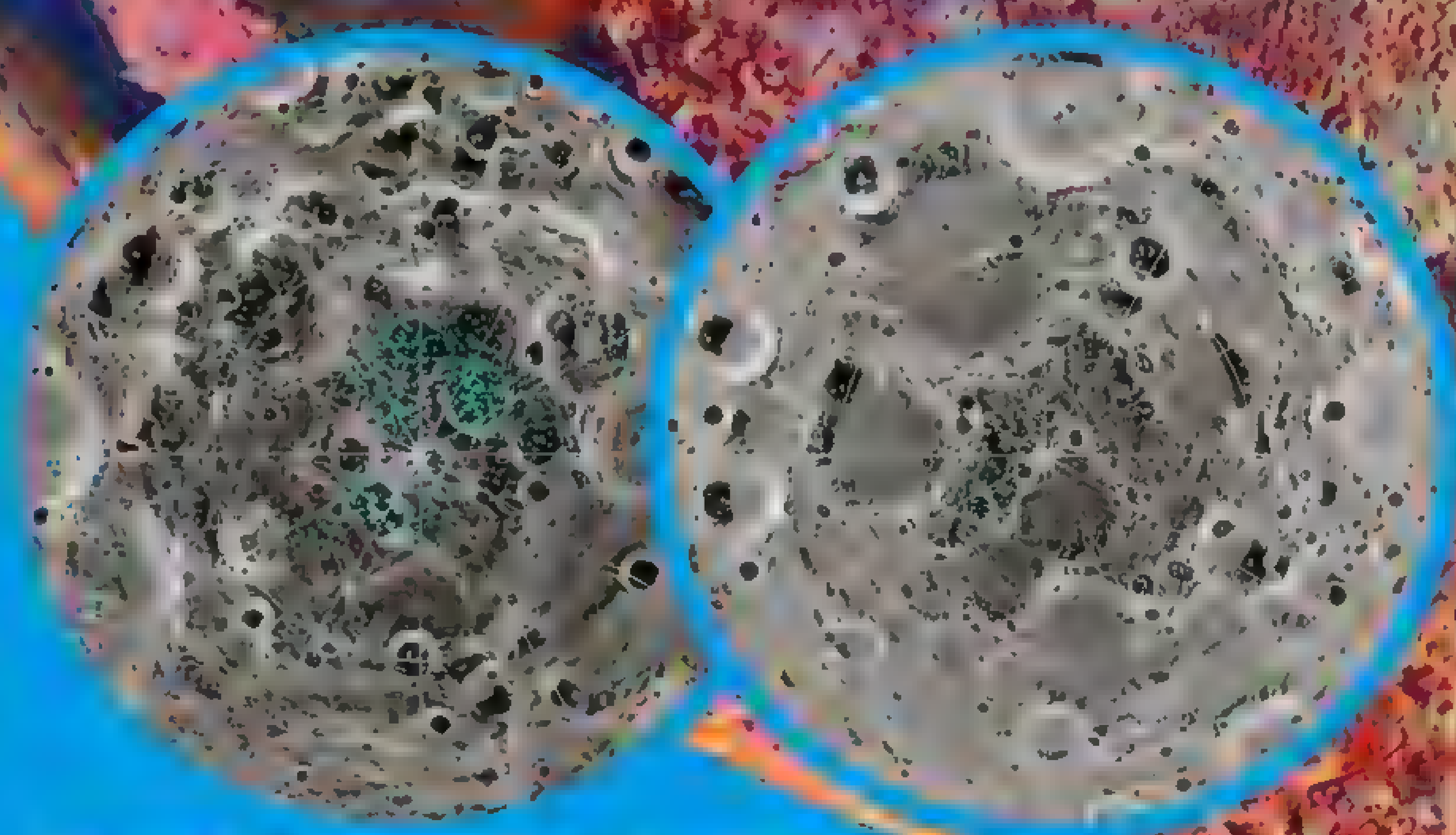
A future lunar base will look to utilise the valuable resources at the poles

Water ice found at lunar poles

From data collected by the Indian Space Research Organisation's Chandrayaan-1 spacecraft, launched in 2008, scientists have found definitive evidence of water ice located at both poles of the Moon.

Courtesy of NASA's Moon Mineralogy Mapper (M3) instrument, scientists were able to detect the presence of solid ice. The instrument was able to locate the reflective properties expected from ice and also differentiate between liquid water or vapour and solid ice based on the distinctive way its molecules absorb infrared light.

These sources are located in the shadows of craters near the poles, where temperatures never get above -157 degrees Celsius. This has tantalising implications for any mission back to the Moon, as the water could possibly be used as drinking water or even rocket fuel for future exploration.



The blue spots represent the ice observed at the Moon's south (left) and north (right) poles.

What is interferometry?

How this clever technique can create a telescope over half the size of Earth

When it comes to telescopes, the bigger the better. A larger primary mirror or objective lens (in optical telescopes) or antenna (in radio telescopes) collects more light or radio waves, resulting in more detailed images. But building massive telescopes is incredibly expensive, and beyond a certain size it simply becomes impractical.

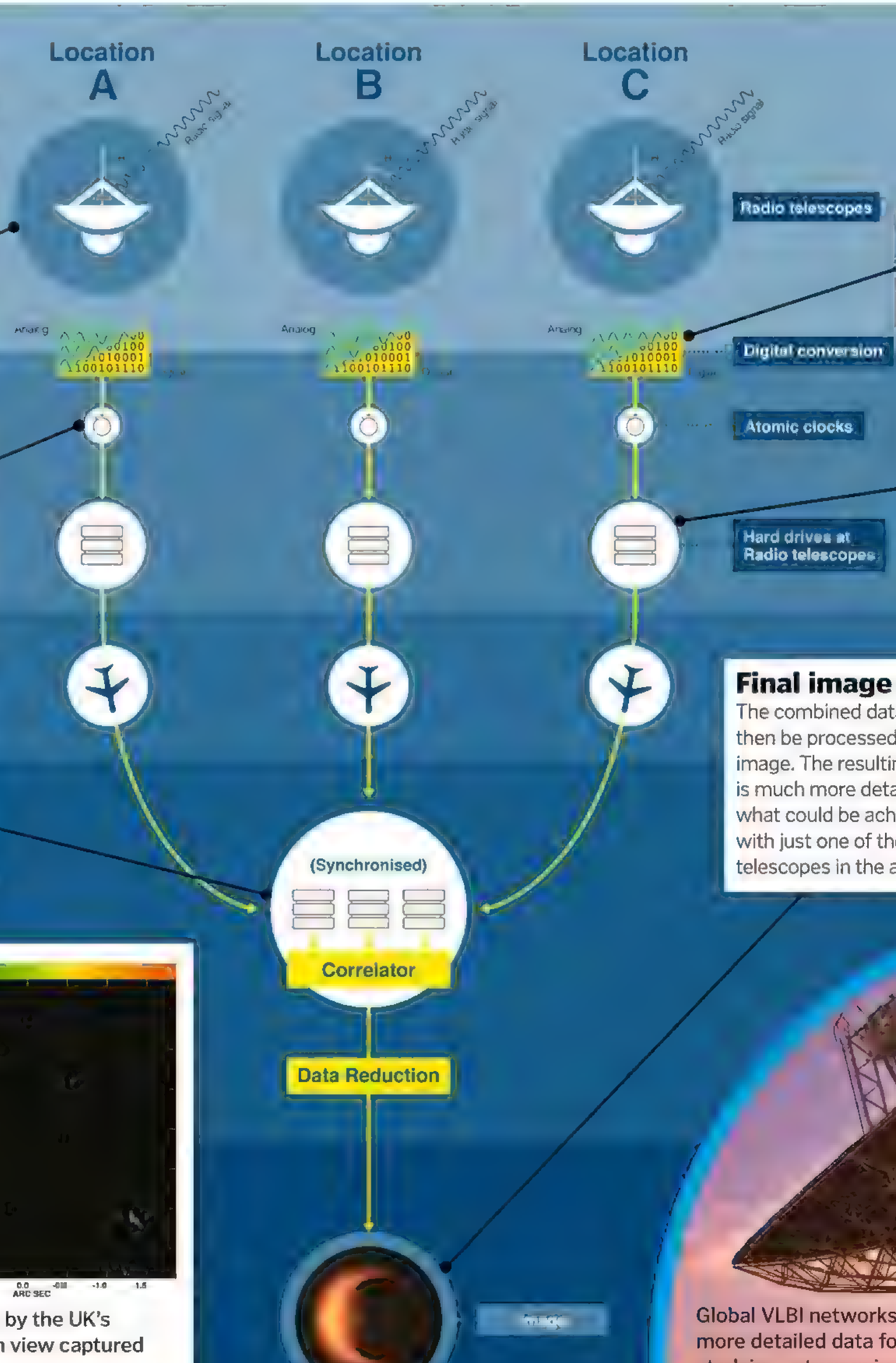
To be able to view the Moon in enough detail to spot the lunar landers, for example, you would need an optical telescope with a 60-metre-diameter mirror. To put this in context, the largest optical telescope on Earth – the Gran Telescopio Canarias – has a 10.4-metre mirror, and the orbiting Hubble telescope's is only 2.4 metres wide.

A technique called interferometry can overcome this problem. If you can combine the light collected by two telescopes positioned 60 metres apart, you will see the same amount of detail as a single 60-metre-wide telescope. In optical interferometry the telescopes must be physically connected to combine the data, which can limit how far apart they can be placed. With radio interferometry, however, the signals can be combined remotely at a later date, so the telescopes themselves can be placed anywhere in the world.

Very long baseline interferometry (VLBI) uses networks of linked radio telescopes positioned very far apart – often across entire continents or hemispheres, or even in orbit – in order to view the universe in much greater detail. One of the largest VLBI systems is the Very Long Baseline Array (VLBA), which consists of ten radio telescopes in Hawaii, across the mainland US, and the Virgin Islands. This system can provide the same level of detail as a single telescope over 8,600 kilometres wide!

How VLBI works

Interferometry makes radio telescopes greater than the sum of their parts



Radio telescopes
The linked antennae collect radio waves from a specific target in the universe. They are not restricted by physical connections so can be positioned anywhere in the world.

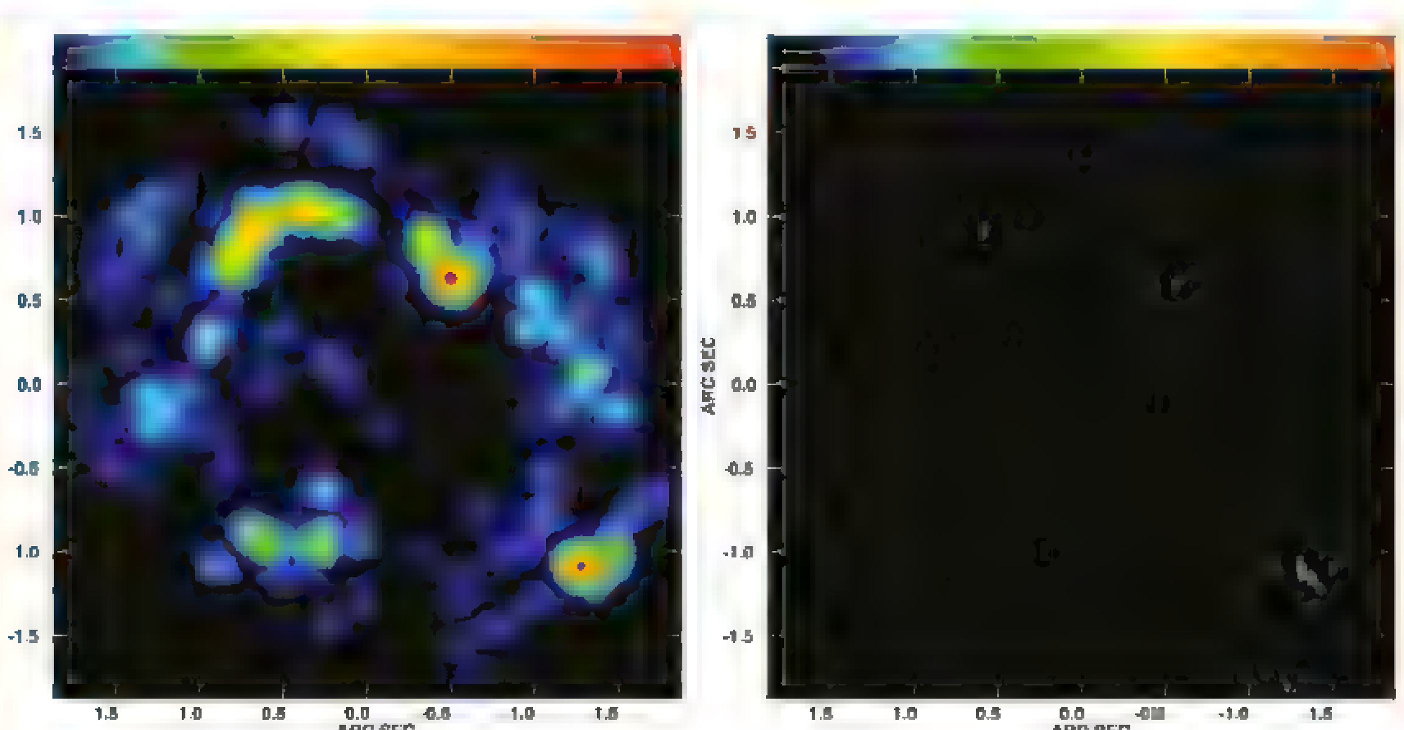
Digitising the signals
The radio antennae collect analogue signals, which are then converted into digital data.

Atomic clocks
Each telescope in the array has an atomic clock, which provides ultra-precise time measurements of each observation.

Hard drives
The digitised radio data and the time stamps from the atomic clocks are stored on hard drives at each telescope site.

Combining the data
The hard drives from each telescope are shipped to a specific location to be synchronised. However, in some networks it is now possible to combine the telescope data in real time with gigabit-per-second fibre-optic connections, known as e-VLBI.

Final image
The combined data can then be processed into an image. The resulting image is much more detailed than what could be achieved with just one of the radio telescopes in the array.



The radio emissions of an expanding gas shell seen by the UK's MERLIN array (left), and the much higher-resolution view captured by the European VLBI Network (right)

Global VLBI networks provide more detailed data for studying astronomical radio sources such as galaxies, black holes and quasars

SPACE W

How radiation from the Sun and supernovae pose a constant threat to life on our planet

Our universe can seem like a somewhat benign place, but phenomena in our Solar System and beyond can have a serious impact on life on Earth. Eruptions from the Sun and cosmic rays from afar can cause havoc with our atmosphere, affecting not just satellites and astronauts in orbit but life on Earth too. Over the years we've been getting better at predicting space weather, but the risk to Earth is ever present. So we can never be too prepared for the next big event that heads our way.

Space weather refers to a lot of things, although it often relates mostly to the Sun, which has the most direct effect on Earth. While our star happily burns away and provides us with both light and heat, it can on occasion erupt in a violent explosion. One such event is a solar flare, when a build-up of magnetic energy is released. These normally erupt from sunspots, which are dark and relatively cool regions on the Sun's surface. Flares are exceptionally bright, releasing large amounts of photons and other particles in our direction, and they can last from minutes to hours. They are categorised in a variety of classes, with the most powerful being X-class flares.

Another type of eruption from the Sun is a coronal mass ejection (CME). These are

EATHER

Words by Jonny O'Callaghan

sometimes associated with solar flares, although the exact relationship is unknown. CMEs, like solar flares, are also the result of magnetic fields building up, but they instead hurl large amounts of matter into space. They can look like large fans of gas zooming out, with the hot plasma they produce taking up to three days to reach us. Using telescopes we can see and monitor both solar flares and CMEs before they reach Earth.

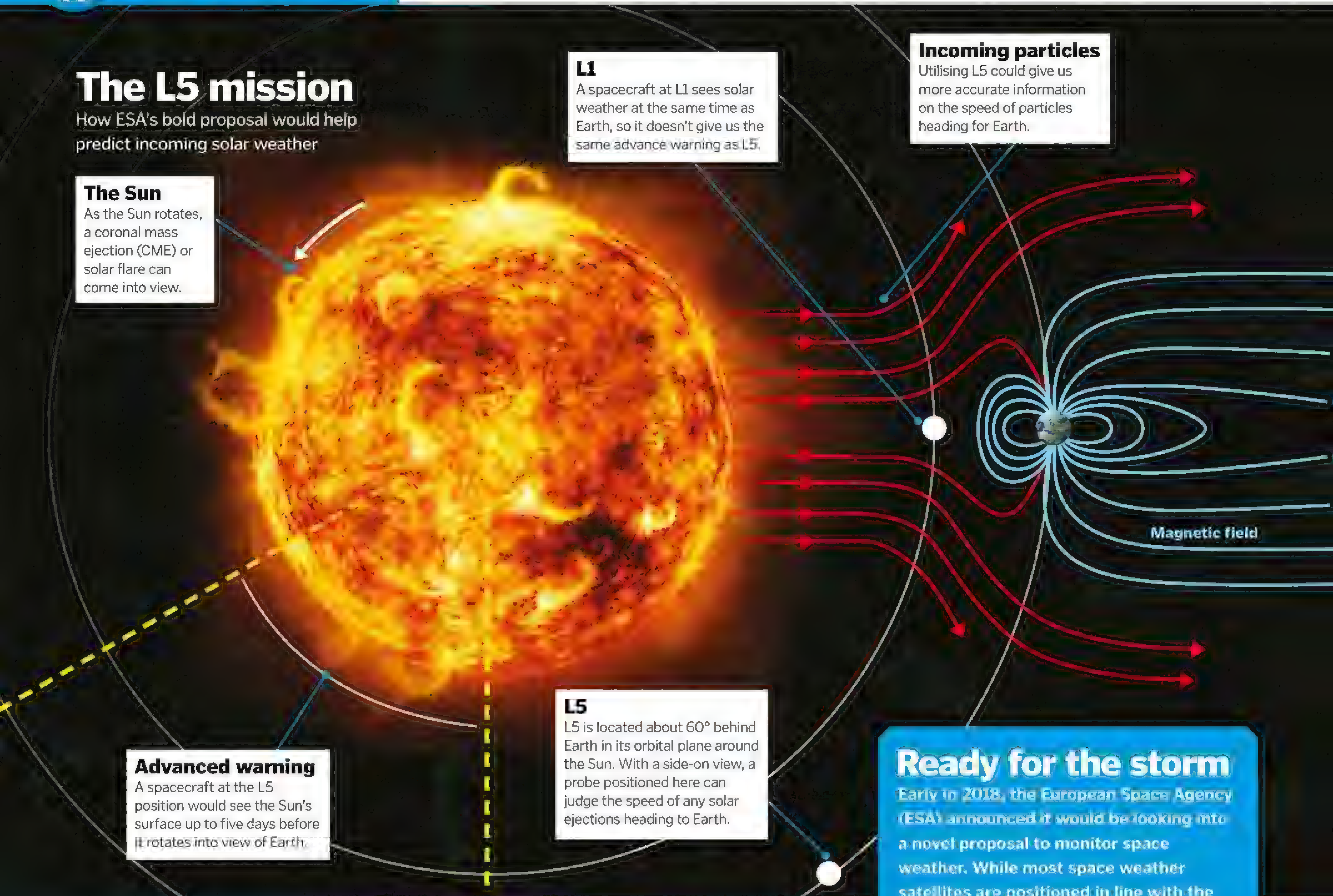
The Sun can produce other space weather too. High-speed solar wind, appearing over holes in the outer atmosphere (corona) of the Sun, can head towards Earth at speeds of up to 800 kilometres per second. Solar energetic particles (SEPs), meanwhile, are high-energy particles that can be caused by both solar flares and CMEs. Carrying a large amount of energy, they can cause considerable damage if they directly hit a spacecraft.

From outside our Solar System, galactic cosmic rays (GCRs) can also be sent in our direction. These highly energetic particles constantly bombard our planet and are thought to be produced by explosive events like supernovae. When the Sun is at its most active, known as its solar maximum, it does a good job of deflecting GCRs from our planet. However, during a solar minimum every 11 years, Earth is more at risk from GCRs,

©Getty

The L5 mission

How ESA's bold proposal would help predict incoming solar weather



Solar eruptions can produce stunning auroras near the poles

Ready for the storm

Early in 2018, the European Space Agency (ESA) announced it would be looking into a novel proposal to monitor space weather. While most space weather satellites are positioned in line with the Sun and Earth, this mission would be placed in a position of gravitational stability lagging behind Earth's orbit, known as Lagrange Point 5 (L5).

No mission has gone to this region before, but it offers a number of benefits. Being positioned to the 'side' of the Sun (relative to Earth), it could give us an early warning of the speed and direction of an ejection heading our way. This is because it could see the eruptions on the side of the Sun before it rotates into our view, so we'd know what was about to head our way. The ESA hopes to select a final design for the mission in mid-2019.

ESA's L5 mission will be positioned behind Earth in its orbit around the Sun

which, like SEPs, can damage spacecraft. Fortunately, thanks to our atmosphere they pose little threat to us on Earth, but astronauts travelling into space in the future may have to contend with them a bit more.

All of these space weather events can have an impact on Earth, from minor to major. The most noticeable are the auroras produced at the north and south poles as particles from a CME release other particles trapped in our planet's magnetosphere, which in turn funnel down to the poles and trigger reactions in oxygen and nitrogen molecules. The result can be a stunning light show of flashing green and purple. However, these geomagnetic storms can also affect communications with spacecraft and expose people flying in planes to more radiation. Flights are even sometimes rerouted to avoid their worst effects.

During periods of intense space weather the number of high-energy particles around Earth increases, particularly in two bands of trapped radiation that surround our planet known as the Van Allen belts. If a high-energy particle strikes a satellite in just the right way it can cause anomalies such as switching a circuit, or more seriously it can damage or knock out the satellite entirely. Sometimes satellites are put into safe mode during the strongest space weather events to protect them from the incoming radiation.

Knowing when these events will occur is therefore very important in order to allow us the time to prepare satellites to ride out the storm. Some severe events can also affect communications and power grids on Earth, which must be similarly maintained to avoid damage.

To track space weather events we have a number of spacecraft that continually monitor the Sun, each one looking for any eruptions that might send particles our way. This can give us several days' warning for the most powerful events, with the National Oceanic and Atmospheric Administration (NOAA) giving storms a rating from 1 (minor) to 5 (severe) to let people know how dangerous an incoming storm is.

Over the years we've certainly got better at monitoring space weather, but there is always the risk of an exceptionally large solar eruption in the future causing huge issues. We can mitigate most problems, but it's always better to be prepared if and when the next big one does hit.

Major space weather events

In 1859, a solar storm known as the Carrington Event struck Earth, causing one of the largest geomagnetic storms on record. At the time it only resulted in a few telegraph pylons emitting sparks, but were the same event to happen again today the results to our infrastructure could be catastrophic.

The Carrington Event was so powerful that, by some accounts, the auroras it produced were bright enough to read a newspaper by. But it's the impact on the ground that is of most concern. The high-energy particles from such an event would ionise our upper atmosphere, sending radio communications haywire. Any associated radiation could pose a danger to astronauts in orbit, while slower-moving charged particles could cause huge disruptions, enough to bring down the electrical grid.

Fortunately, we're getting better at predicting storms like this, so hopefully if one happens again we'll be ready.

A modern Carrington Event could knock out our electric grid

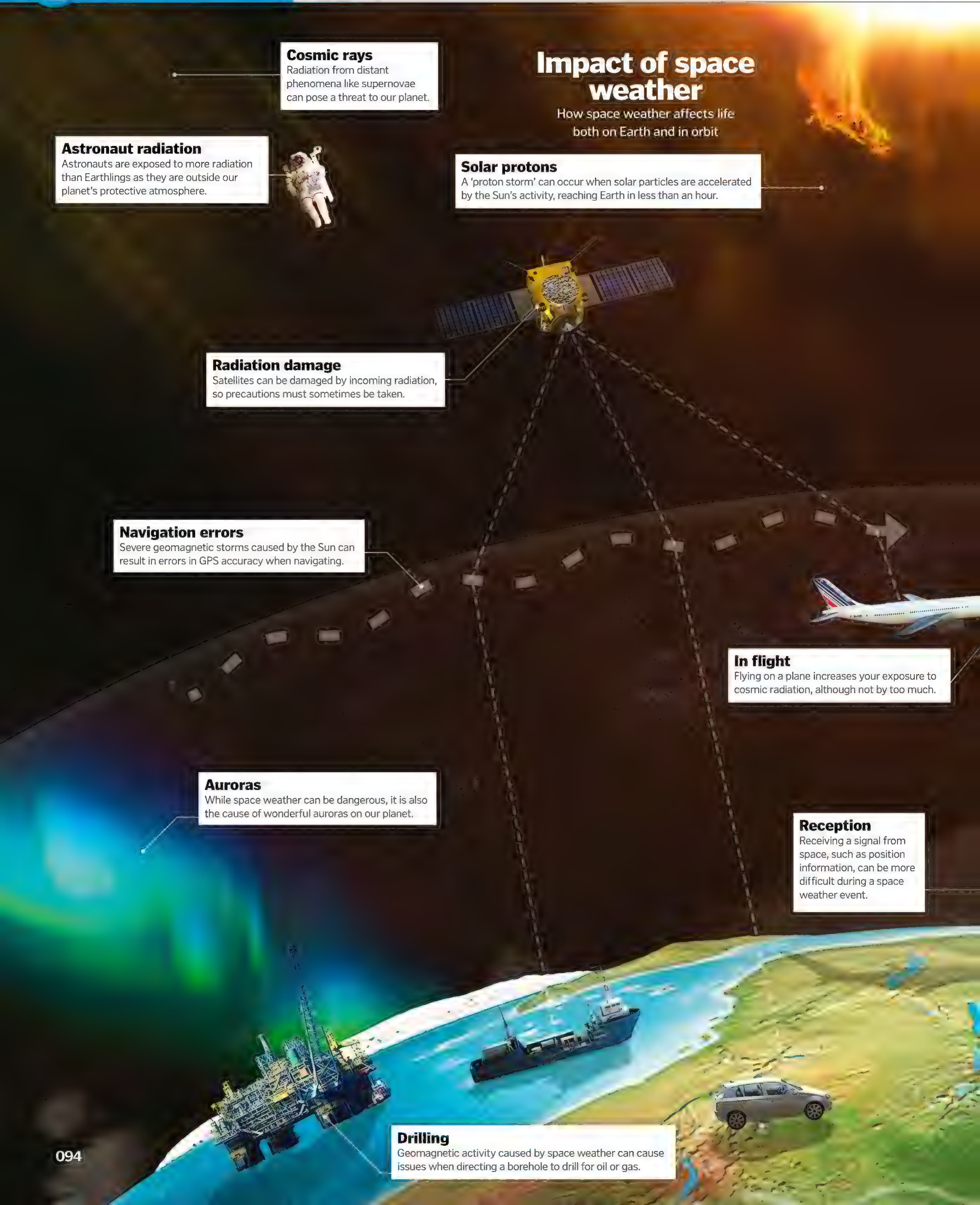
Astronauts on a spacewalk can be at risk from space weather

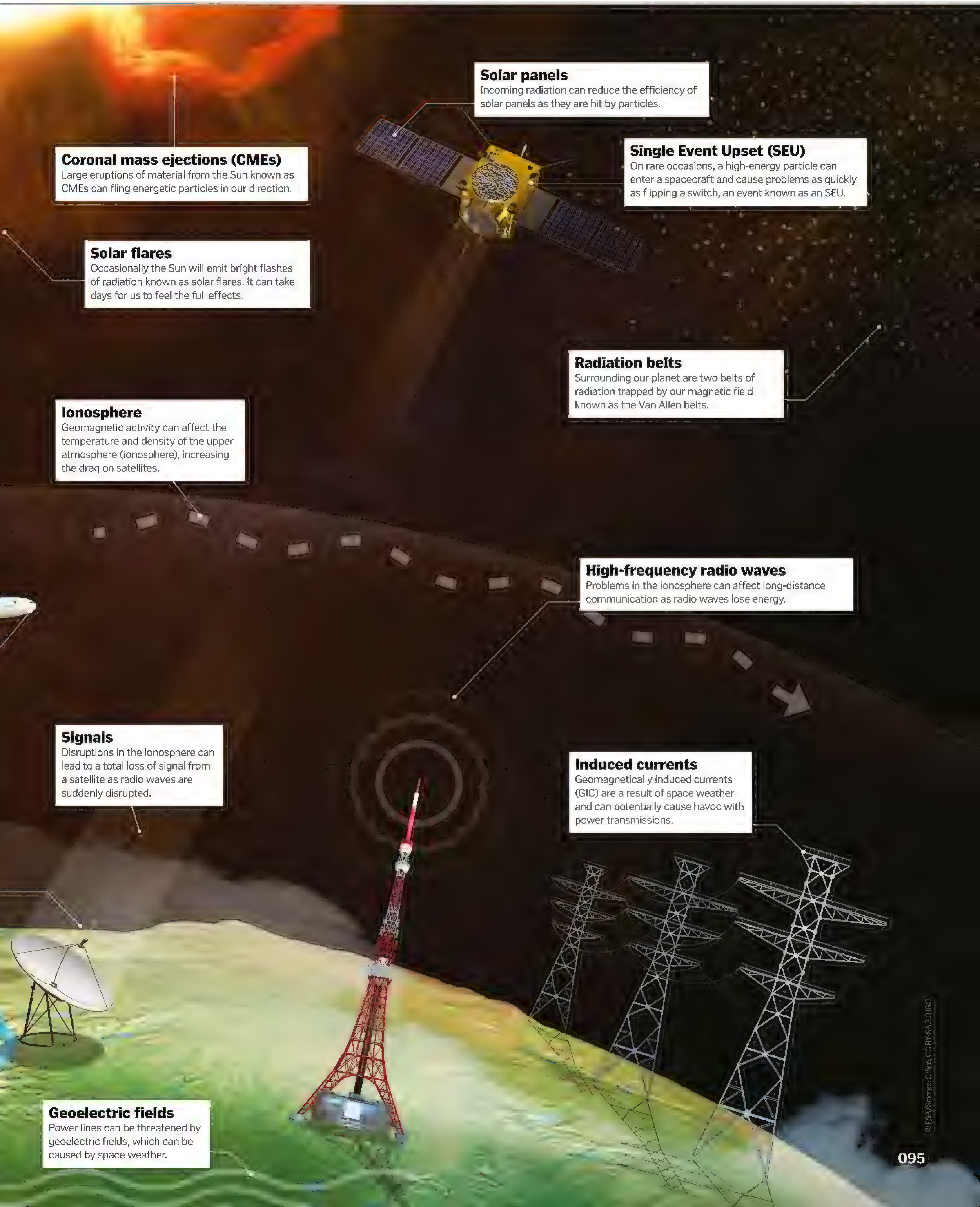
Spacecraft like the ESA/ NASA Solar and Heliospheric Observatory (SOHO) help us predict space weather

Solar flares can appear extremely bright on the Sun's surface

Impact of space weather

How space weather affects life both on Earth and in orbit




Solar panels
Incoming radiation can reduce the efficiency of solar panels as they are hit by particles.
Coronal mass ejections (CMEs)
Large eruptions of material from the Sun known as CMEs can fling energetic particles in our direction.
Single Event Upset (SEU)
On rare occasions, a high-energy particle can enter a spacecraft and cause problems as quickly as flipping a switch, an event known as an SEU.
Solar flares
Occasionally the Sun will emit bright flashes of radiation known as solar flares. It can take days for us to feel the full effects.
Radiation belts
Surrounding our planet are two belts of radiation trapped by our magnetic field known as the Van Allen belts.
Ionosphere
Geomagnetic activity can affect the temperature and density of the upper atmosphere (ionosphere), increasing the drag on satellites.
High-frequency radio waves
Problems in the ionosphere can affect long-distance communication as radio waves lose energy.
Signals
Disruptions in the ionosphere can lead to a total loss of signal from a satellite as radio waves are suddenly disrupted.
Induced currents
Geomagnetically induced currents (GIC) are a result of space weather and can potentially cause havoc with power transmissions.
Geoelectric fields
Power lines can be threatened by geoelectric fields, which can be caused by space weather.

What is string theory?

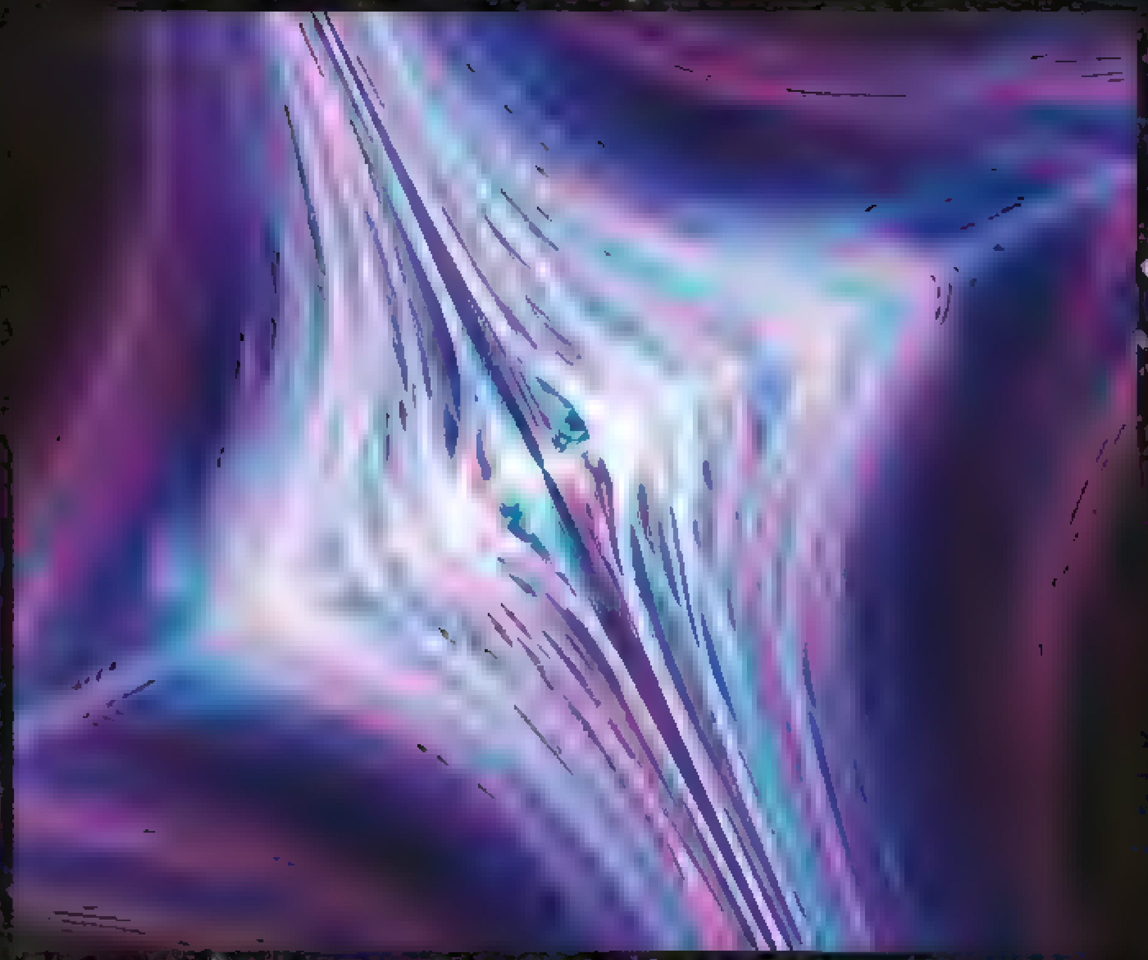
Could this strange idea explain how the entire universe works?

String theory, or more accurately superstring theory, is the idea that elementary particles like electrons are made up of vibrating strings of energy. While we once thought elementary particles were the smallest things possible, string theory suggests that there is something even smaller that makes up the universe around us.

The theory is also known as M-theory, and it's intended as a way to explain some of the limitations of the Standard Model of physics. This is the model we use to explain how everything in the universe works, but it breaks down when we look at things at a quantum level – the level at which weird effects take place, like particles appearing in two positions at once (called superposition) or being able to share information over great distances (called entanglement).

As the strings move through time they vibrate in one dimension in different patterns, or 'modes'. Each one of these can make the string appear like an electron, a photon, and so on. At bigger scales these strings simply look like particles to us. Some suggest string theory could be the much-sought-after 'theory of everything'. It can also explain how two particles of gravity, known as gravitons, can interact on large scales, when other theories cannot.

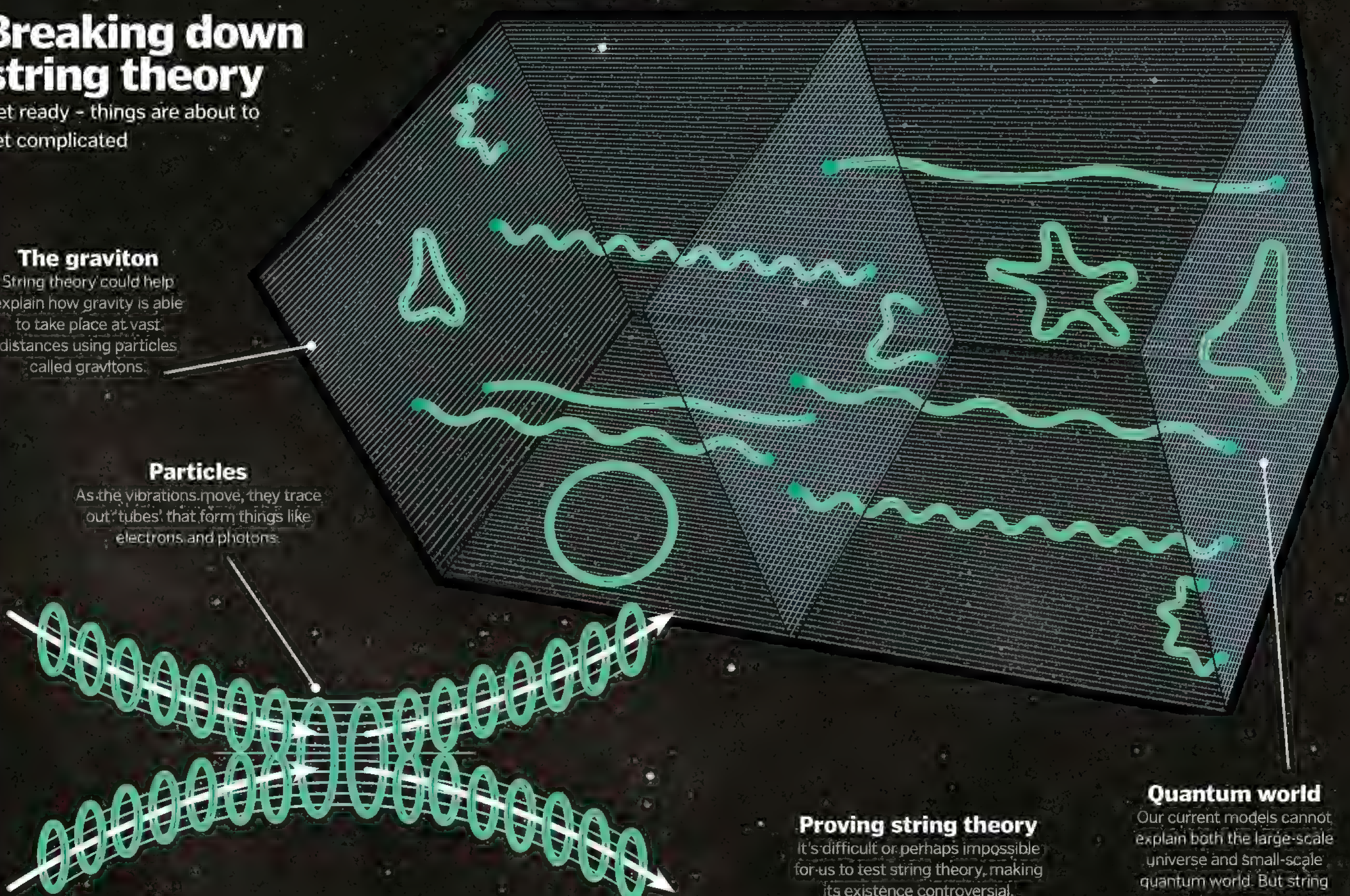
Not everyone believes in string theory, however. One notable problem is that it requires space-time to have at least ten dimensions, six more than our standard four: three for space and one for time. It's suggested that these extra six dimensions are so compact that we don't even know they're there. Plus, it's very hard to prove. We can't really measure these strings, so how will we ever know that they exist? Nonetheless, string theory continues to be debated by the scientific community.

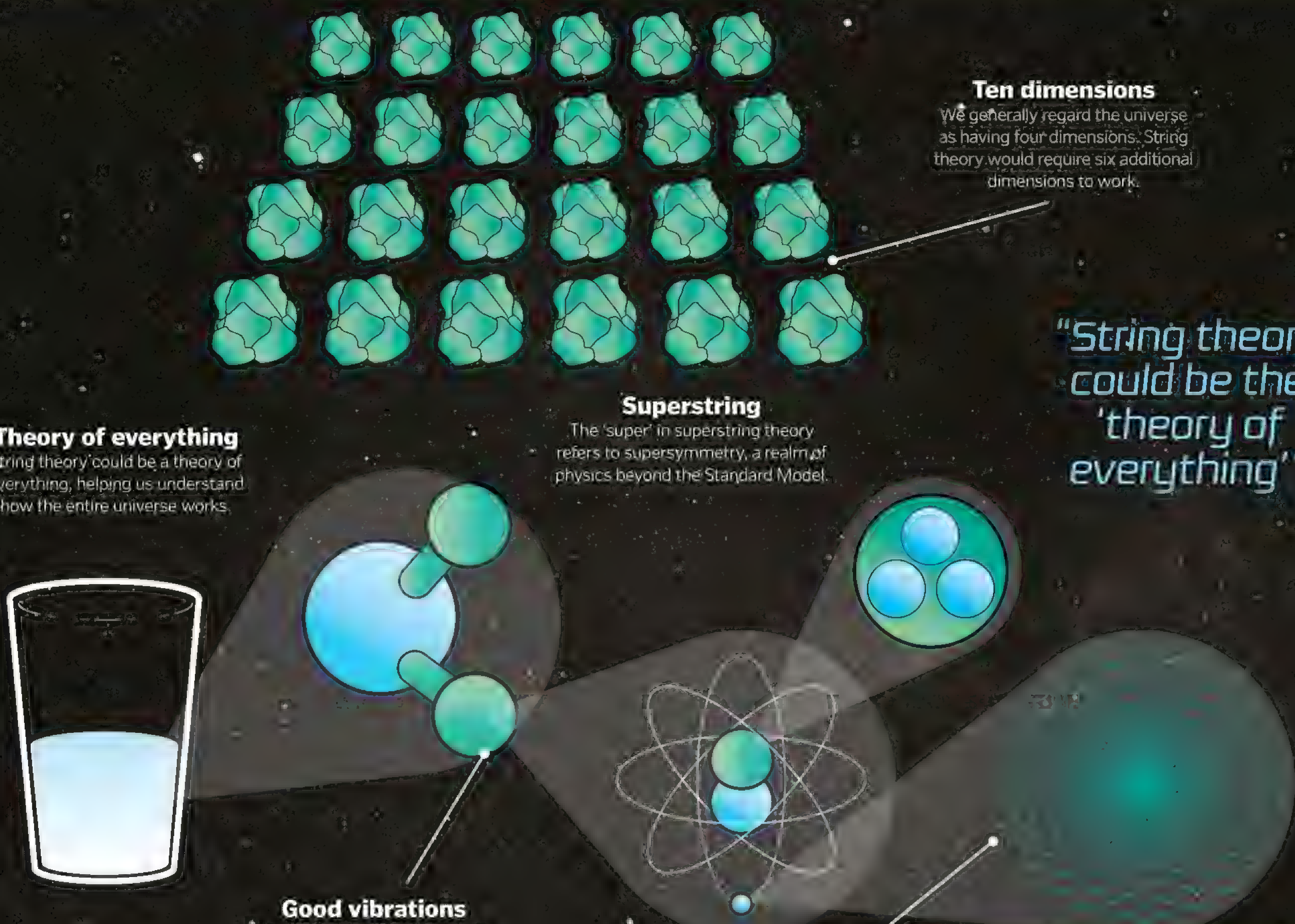


In string theory, everything is composed of vibrating strings of energy

Breaking down string theory

Get ready – things are about to get complicated





Ten dimensions
We generally regard the universe as having four dimensions. String theory would require six additional dimensions to work.

> "String theory could be the 'theory of everything'"

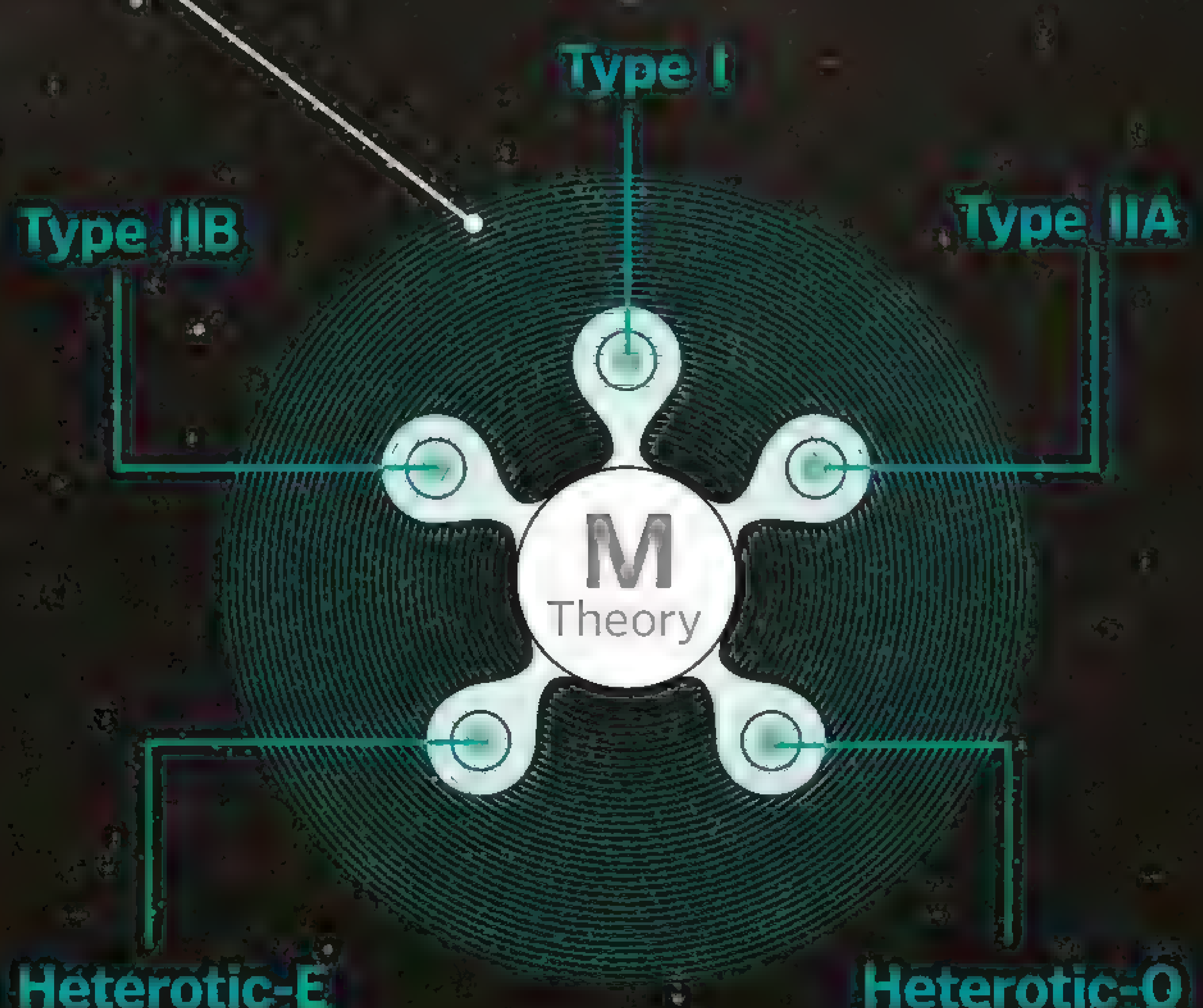
Theory of everything
String theory could be a theory of everything, helping us understand how the entire universe works.

Superstring
The 'super' in superstring theory refers to supersymmetry, a realm of physics beyond the Standard Model.

Good vibrations
According to string theory, all particles can be broken down into vibrating strings of energy.

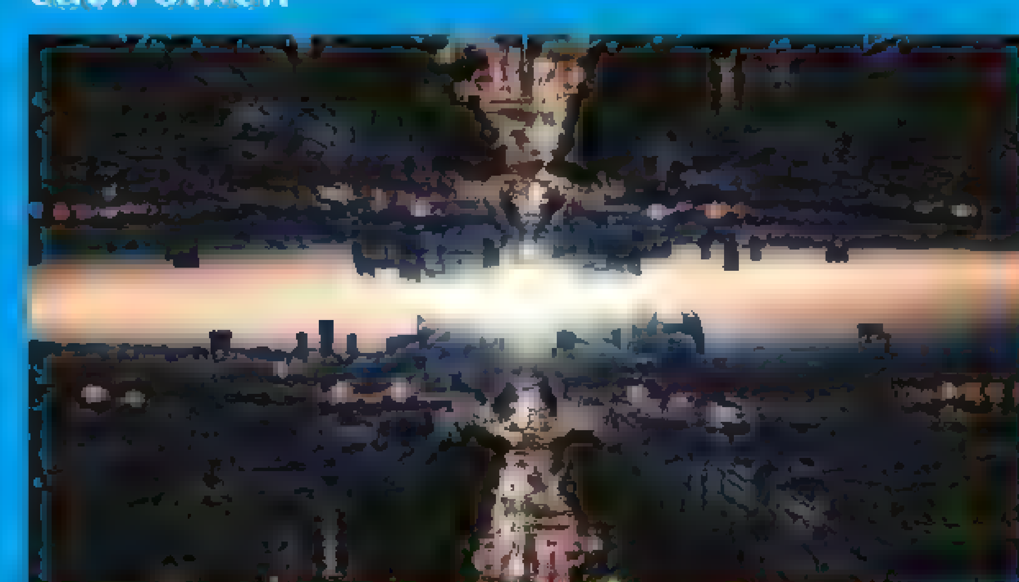
Bad vibrations
But under string theory, these vibrations are so small that we can never actually see them.

M-theory
Modern string theory is generally regarded as M-theory, which involves 11 dimensions.



Parallel universes

String theory isn't the only controversial theory on the block. Another is the many-worlds interpretation, which suggests that the universe has an almost infinite number of parallel universes. First put forward in 1957, it suggests that everything is quantum, meaning that things can occur in multiple ways simultaneously. If you apply this at both a small and a large scale, it means that all possibilities in any given scenario should occur, with each giving rise to a universe that is equally real. Under some versions of the theory it could actually be possible to see the effects of parallel universes on each other.



The many-worlds theory predicts there are near-infinite parallel universes

HOLLYWOOD VS SPACE

What the silver screen has got right and wrong about the final frontier

Words by **Jonathan O'Callaghan**

DID YOU KNOW? *A page of the script for The Martian flew on NASA's Orion spacecraft test flight back in December 2014*

THE MARTIAN

When Mark Watney (played by Matt Damon) becomes stranded on Mars, he must use his wits to survive in an extremely dangerous environment. The 2015 film is based on a book of the same name by author Andy Weir, who admitted he made one big concession to get the story rolling. The storm that strands Watney on Mars was depicted as having gale-force winds, but the thin atmosphere means that the winds would be almost negligible, so Watney probably would have been fine. Watney's movements on Mars also don't recreate how humans would really move on a planet with a third of Earth's gravity – he'd probably be hopping and shuffling around more than walking or running.

It did get a lot right though. For starters, the orbital dynamics of getting to Mars and back to Earth – complete with a risky slingshot manoeuvre – are spot on. As for using Martian soil to grow potatoes, this could also be possible, as scientists in Peru demonstrated in 2017. The movie also accurately depicted 'tornados' on Mars, which are very real and are known as dust devils. The idea of using inflatable habitats on the surface is also something NASA has been considering, although some have suggested they may need to be more rounded in shape to cope with the low pressure.

Author Andy Weir stated that his research for the science behind *The Martian* influenced some of the story's plot points

APOLLO 13

Apollo 13 is widely regarded as one of the great space films, retelling the dramatic story of the ill-fated NASA mission in both exciting and accurate fashion. But did it get everything right? Well, not quite. The film is praised for its depictions of all the equipment in the mission, from the spacecraft itself to the flight control room. Many of the characters in the film also bore a resemblance to their real-world counterparts. The actors even took a course in physics to ensure they were up to speed with the script.

There were a few minor errors though. Perhaps the most infamous is the use of the line, "Houston, we have a problem." That was never actually said during the mission, with the actual line from Jim Lovell (played by Tom Hanks) being, "Houston, we've had a problem." The far side of the Moon is also incorrectly called the dark side, with it not actually being in darkness during the mission. The film also made it look like NASA had to come up with a lot of things on the fly, when in fact they already had procedures for a lot of the problems they faced. Still, it didn't do a bad job compared to some other films.

Apollo 13 tells the true story of how the mission's astronauts dealt with a disastrous oxygen tank explosion

GRAVITY

In 2013's *Gravity*, our heroine Sandra Bullock must survive in Earth orbit when space junk goes haywire in a film that gets some key things right, notably on the technical side.

Its depictions of the International Space Station (ISS) and the Hubble Space Telescope are exquisite, as are its attention to detail on the spacesuits and spacecraft like the Soyuz capsule. The idea of space junk causing a chain-reaction effect like this in orbit is also very real, and it's called the Kessler syndrome. Some experts think that our debris in orbit could become so great that this becomes a near certainty in the future.

However, the film gets a lot wrong, most notably that the protagonists are able to travel between Hubble, the ISS and the Chinese Tiangong-1 space station with ease. In reality there's no feasible way to get between these locations in orbit as they're separated by vast distances. What's more, the film suggests a Kessler syndrome in low Earth orbit (LEO) would knock out communications satellites, but LEO is just a few hundred kilometres up, whereas communications satellites orbit at altitudes of around 35,000 kilometres above Earth.

> *"The idea of space junk causing a chain-reaction is very real"*

The ISS looked great in Alfonso Cuarón's *Gravity*, but the science was not spot on

2001 did a good job of showing what space travel is really like

2001: A SPACE ODYSSEY

Stanley Kubrick's 1968 film is highly regarded, and for good reason. The film did a wonderful job of depicting space travel, from the slow, silent and somewhat monotonous journeys to simple things like the communications delay back home. Its depiction of an orbiting space hotel wasn't bad at all either, with a large rotating structure being used to simulate gravity. It even predicted the arrival of the Space Shuttle, although we haven't quite reached the Pan Am heights touted by Kubrick – yet. As for Hal, you've only got to talk to your Alexa or Google Home personal assistant to see how rapidly technology is catching up to this vision of the future, although hopefully without all the killing and whatnot.

INTERSTELLAR

All you need is love. At least, that's what Christopher Nolan would have us believe in his 2014 film *Interstellar*. Sure, the film looked great, but did it get everything right? A bit.

First up, the centrepiece of the film: the black hole. It's well documented that the team got theoretical physicist Kip Thorne (2017 Physics Nobel Prize laureate) onboard to model the black hole, which actually spawned a couple of papers. How it looked, with the light bending around it, was probably quite accurate based on what we know. As for falling into it, well, whether a person could survive the stretching of space and time – known as spaghettification – is up for debate. Planets orbiting a black hole also seems feasible, although it's questionable if they could be habitable.

As for the interstellar travel itself, the idea of wormholes is not beyond the realms of fantasy, although they do remain purely theoretical. The spacecraft itself seemed mostly fine, except for the fact it needed a rocket to escape Earth's gravity but could escape the intense gravity of a 'black hole planet' with no rocket required. As for the theory of time dilation – that the astronauts would age slower than us on Earth – well, this is fairly well established and enshrined in the known laws of physics thanks to Einstein. Not bad, Nolan.

> "Whether a person could survive spaghettification is up for debate"

The depiction of *Interstellar*'s black hole, Gargantua, was praised for its scientific accuracy

ARMAGEDDON

Where to start, as 1998's *Armageddon* gets so much wrong it is almost unbelievable, with an estimated 168 inaccuracies in its 150 minutes. One of the biggest is the size of the asteroid itself, said to be as large as Texas. How would no one spot that approaching Earth? Then we have the attempt to blow up the asteroid using nukes, which simply wouldn't have worked. You'd be much better off trying to move it way in advance with a small nudge. Even if they did blow up the asteroid, those pieces wouldn't go anywhere – they'd still rain down on Earth and cause untold damage. The approach to space exploration in this film is also terrible, with space shuttles flying around like planes. If we were giving ratings for scientific accuracy, this film would get a Texas-sized zero.

"*Armageddon gets so much wrong it is almost unbelievable*"

Highly questionable science didn't stop *Armageddon* grossing $553 million at the box office

SUNSHINE

The premise of this 2007 film might seem absurd: our Sun is dying, and life on Earth is doomed unless we can restart it. However, it's kind of based on theory, with the film's scientific advisor – a little-known chap back then called Dr Brian Cox – saying they imagined a theoretical particle called a Q-ball that could stop the Sun's core. While it's a bit far-fetched, it's very slightly possible. What's less likely, however, is the plan to restart the Sun by sending a huge nuclear bomb inside it to get its core up and running again. The bomb itself would have melted long before it reached the Sun, and even if it survived, the Sun is huge; we simply couldn't restart it with a bomb. Also, why send humans on this mission at all? It certainly seemed a bit unnecessary as it could have been controlled remotely.

The threat of the Sun looms large in Danny Boyle's *Sunshine*

Bruce Willis makes a decent action hero, but he might want to brush up on his science

Star Trek vs Star Wars

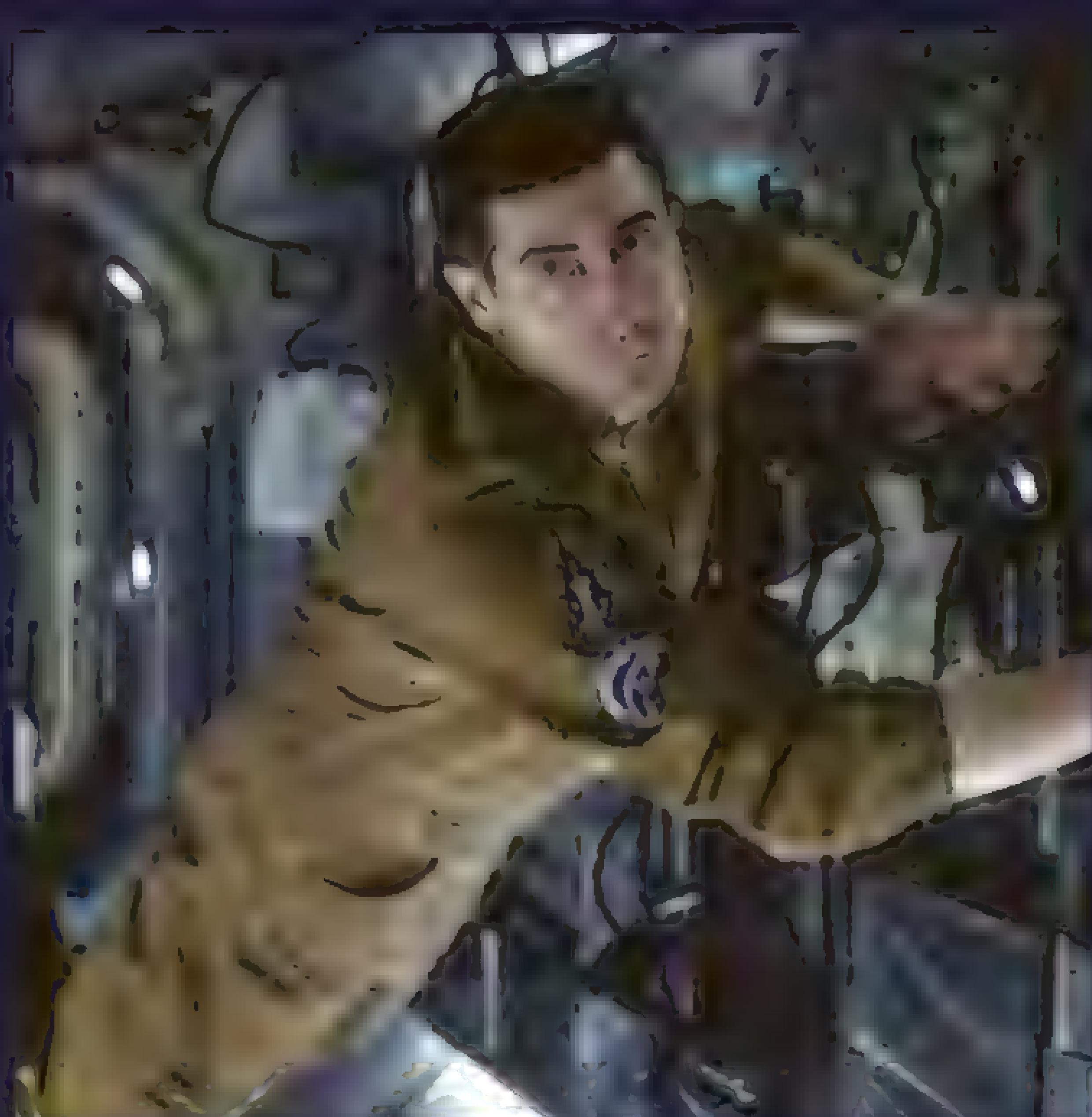
Star Trek is famous for a whole host of technologies, from the transporter to the warp drive. The former is a neat way to get people to the surface of a planet quickly without needing a scene where they fly to the surface, but at the moment transporting matter doesn't look too feasible. Warp travel, or faster-than-light travel, also remains a theoretical concept and one that many don't think will ever be possible. The medical tricorders, though, are something scientists are developing right now – well, at least devices to diagnose people with certain conditions quite quickly.

As for *Star Wars*, things get a bit more fanciful. You're probably not going to be wielding a lightsaber or using the force any time soon, but you might well have a robotic companion like a droid one day given our advancements in artificial intelligence and robotics. It also did a pretty neat job of predicting some of the habitable worlds we are finding outside our Solar System, from strange gas giants to water worlds.

It's a battle as old as time, but which film comes out on top with science?

LIFE

In 2017's *Life*, our heroes must deal with a mysterious Martian organism gone rogue as it wreaks havoc on the ISS. The idea of a sample return mission to Mars as depicted in the film is sort of accurate, and NASA is currently looking at undertaking such a mission in the near future, although the organism would probably be brought back to Earth, not to the ISS. One of the big things it gets wrong, though, is how NASA tries to push the ISS into deep space later in the film. While we do use docked capsules to push the station, you couldn't push it that far, and it probably wouldn't end up re-entering our atmosphere either.



Jake Gyllenhaal and crew try to contain a deadly alien threat in Daniel Espinosa's thriller *Life*

TRANSPORT

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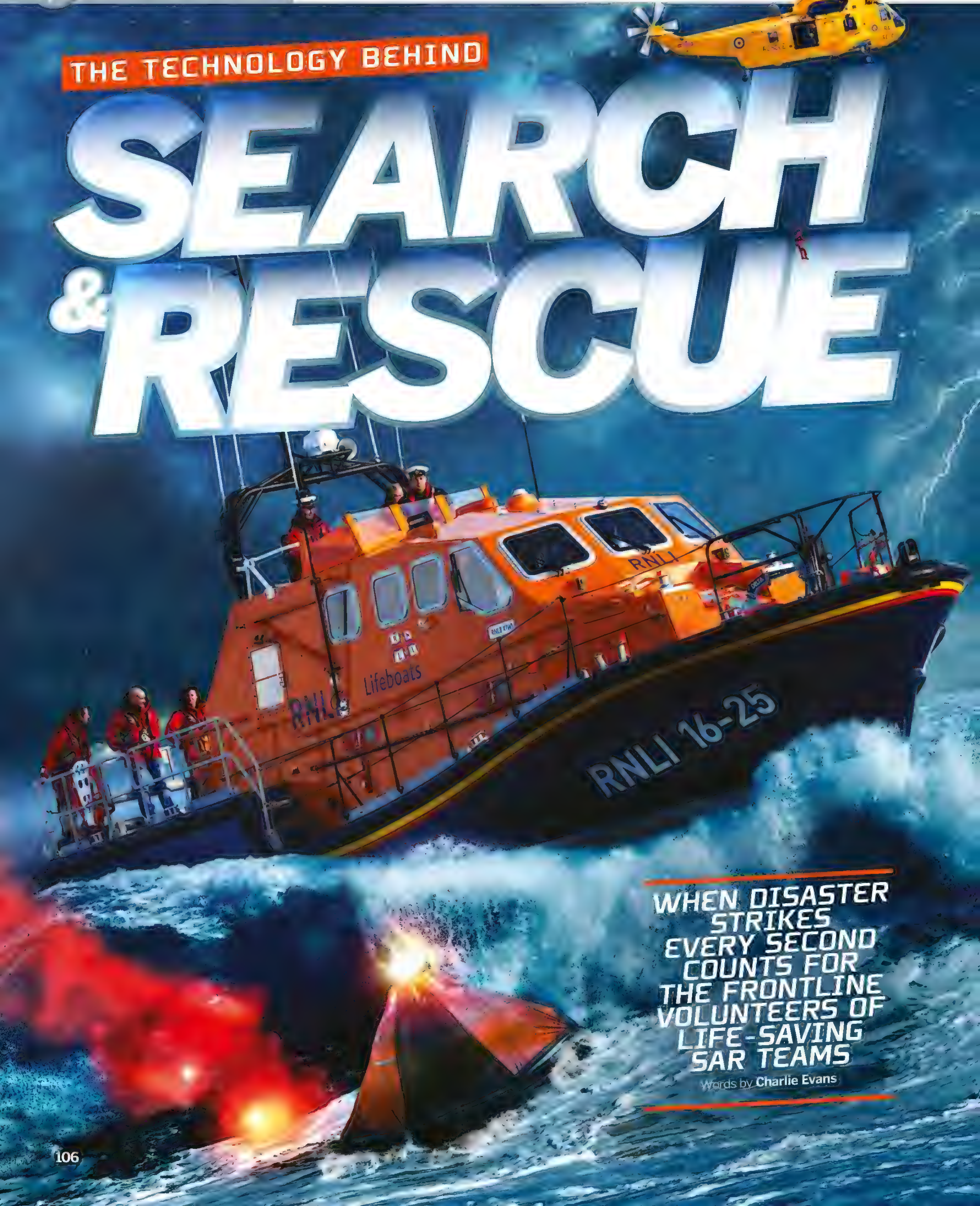
The technology behind search and rescue

THE TECHNOLOGY BEHIND

SEARCH & RESCUE



WHEN DISASTER STRIKES EVERY SECOND COUNTS FOR THE FRONTLINE VOLUNTEERS OF LIFE-SAVING SAR TEAMS

Words by **Charlie Evans**

Huddled inside a cave, a young football team shivers with their knees tucked into their chins and shirts pulled over their legs. The boys and their coach have been trapped for ten days after an expedition into Thailand's Tham Luang cave quickly turned from celebration to disaster.

When monsoon rains hit and the water levels rose, they desperately sought higher ground, squeezing through narrow tunnels and passageways as they were forced further into the cave system. They could find no escape, but about three kilometres from the cave's entrance they found a small rock ledge high enough to keep them safe. In total darkness, they clambered onto the ledge and hoped for rescue. Without food, and with oxygen levels running low, their chances of survival were slim.

There was little hope that the boys were still alive when their bikes were found outside the cave, but the rescuers were determined; in a matter of hours soldiers, doctors and divers assembled among the tents of families and volunteers. Water pumps were carried to the site to try and lower the water levels in the cave. As the boys sat trapped by the water, they had no way of knowing that outside more than 1,000 people from around the world had rallied to their aid, or that the events about to unfold would become one of the greatest rescue missions in recent years.

After dozens of divers scoured the cave, help finally arrived for the boys. A torch pierced the darkness of their chamber, and a British diver emerged from the water shouting: "We are coming. We are the first. You have been here ten days. You are very strong." Sadly, during a dive to take oxygen to the boys, Saman Kunan, a former Thai Navy SEAL, lost his life. This tragedy highlighted the dangers involved in the rescue efforts, even for the most experienced divers. Over the next few days divers took the boys food, water and medical supplies as the world watched on as each one was sedated and removed, held by rescuers who navigated the frozen water and jagged rocks. Then, more than 17 days after they first entered the cave, all 12 boys and their coach emerged alive and into the arms of their families and friends.

The rescue effort captured the world's attention, but it isn't the only one of its kind. Every day, it's estimated that over 600 people go missing globally due to crime, natural disasters or tragedy at sea and on land. This can occur anywhere, from the open ocean to the shoreline, from mountains and forests to caves and countryside. Being part of the teams that search for and rescue people in danger is a job that takes determination, bravery and skill, and it relies on a combination of advanced technology and intense training.

Search and rescue (SAR) teams worldwide work tirelessly to safely return missing people home from being lost on land or at sea. In the UK, the largest SAR organisations consist mainly of volunteers, including the Bristow Group's Helicopter Service, Lowland Rescue and UK SAR. Yet these are just some of the many SAR teams that race against the clock to find those in critical danger and battle some of the world's harshest weather and toughest terrain to save lives – no matter when or where.

A grid search team will inspect smaller areas thoroughly and often find clues to further guide the search

Robots to the rescue

Joining the search for missing people – and pushing the boundaries of search and rescue technology – are squadrons of rescue drones. These 'eyes in the skies' are able to analyse the situation in the aftermath of natural disasters as well as assist in locating casualties and exploring dangerous locations such as collapsed buildings and chemical spill sites.

When it comes to tackling terrain too harsh for humans, these robots are relatively recent additions to the SAR toolkit, but they are aiding rescue missions by providing full HD and thermal-imaging technologies. Martin Kingsbury, a drone pilot with Kent Search and Rescue (KSAR), explains.

"They enable us to gain up-to-date topography of how the land lies, which can be relayed back to our control vehicle by live down-link," he tells How It Works while expertly manoeuvring the drone over a fleet of rescue vehicles. "Drones can search areas where access is difficult or putting teams on the ground would endanger the teams – such as the mudflats on the banks of the River Medway. They can also be used to search premises without contaminating the scene in the unusual event of a crime being committed."

"These are the teams that race against the clock to find those in critical danger and battle some of the world's toughest terrain to save lives"

MOUNTAIN & LOWLAND RESCUE

The search and rescue teams on the ground – tackling rivers, rocks and ravines – form the backbone of the land emergency response

A broken ankle and no phone signal can quickly turn a gentle hill walk into a deadly trek; as the night draws closer and the temperature drops, the ground search and rescue teams are responsible for finding those who have gone missing on land.

Whether you're scrabbling through a cave or traversing a field, you can't carry a giant case with you equipped with everything you need, and the further off the beaten track you stray the harder it becomes to carry equipment. The work for land rescue is much more about relying on your senses and keeping equipment light, so these SAR teams are highly trained to use their observation and intuition and will usually find clues that will direct other searchers as they scour the area.

SEARCH ON FOOT

Searching on foot is almost always the first plan when a person is reported missing. After gaining some information about the missing person, such as their last known location and what clothes they were wearing, a map is divided into search areas before the teams organise themselves. Grid searching is what comes to mind when you think of the hunt for a missing person; a long line of volunteers walking across open fields examining the ground. A trained grid search team can cover approximately 1.6 kilometres in 3.5 hours by walking slowly and deliberately and taking time to survey each bush and debris encountered for vital clues.

The other main type of searching, known as hasty searching, is almost the opposite. As the name suggests, hasty searchers work so fast they are almost jogging, and they explore vast areas and check the most obvious places where a missing person may have been wounded or stopped to rest, such as cliffs, ditches and caves. The teams at UK SAR are trained to identify tracking signs including broken branches and footprints, but when the terrain gets more difficult they can use equipment such as bikes, kayaks and boats to continue their search.

> *"A trained grid search team can cover around 1.6 kilometres in 3.5 hours as they search the area for vital clues"*

COMMUNICATION TECHNOLOGY

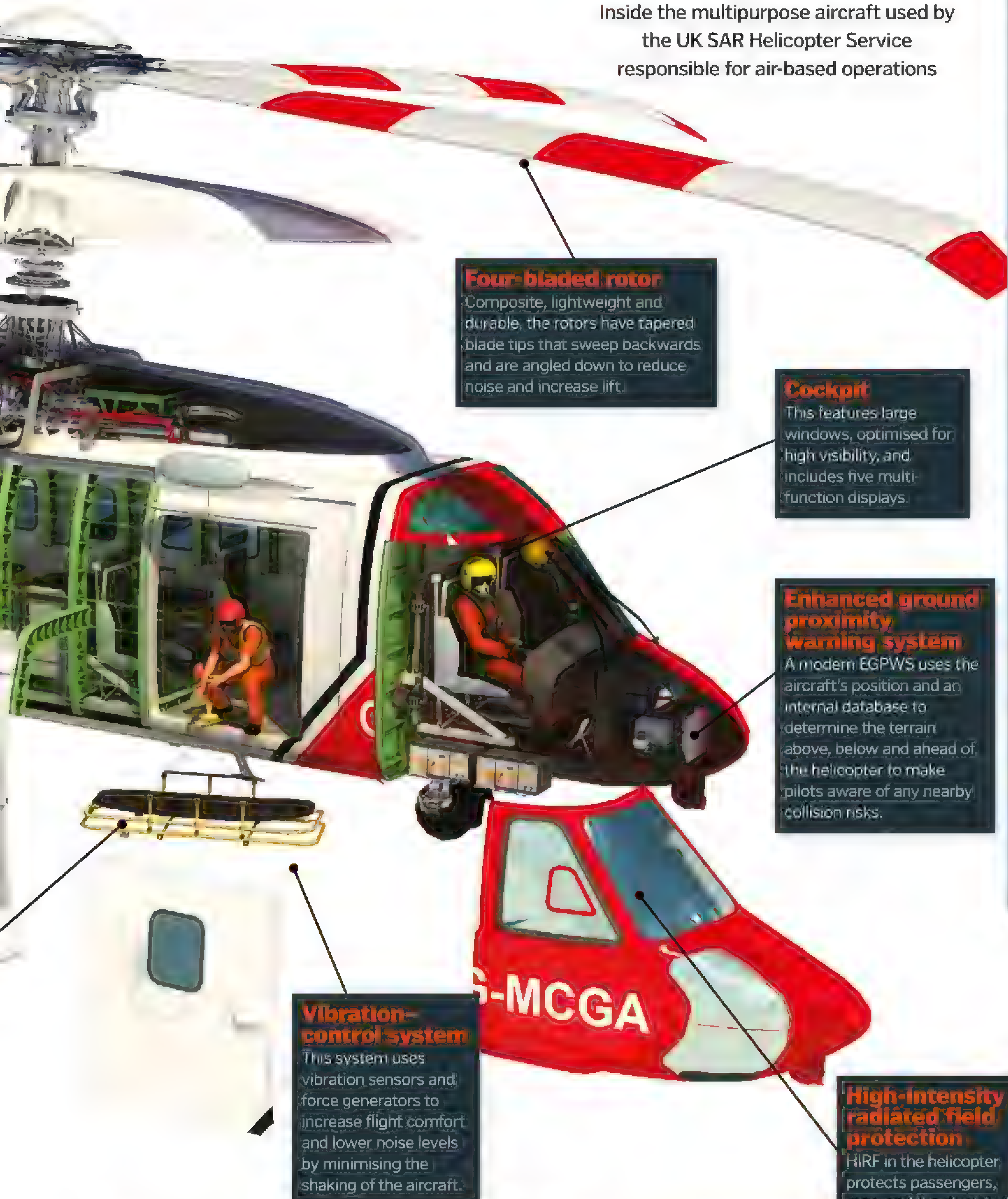
There is some equipment that will always come with a search team, despite the difficulties of carrying it on a search. Gary Mitchell, surface support in the Tham Luang cave rescue, spoke to **How It Works** about the technology they used.

"In any rescue we need to know exactly what is happening underground and where people are and in what direction people are moving, and 'heyphones' were one of our staple pieces of equipment."

Heyphones are commonly used by cave rescue teams, in addition to the more standard VHF radio used by ground rescue, as the low frequency is able to penetrate through rock and deep into the ground using induction loop antennas or electrodes in the ground. Communications become even more important when the missing person is found but isn't in good health. "You need instant comms so you can know the condition of the casualty – if they're getting better or if they're deteriorating."

The Sikorsky S-92 helicopter

Inside the multipurpose aircraft used by the UK SAR Helicopter Service responsible for air-based operations



A helping paw

There is no technology more sensitive than the nose of man's best friend, and SAR dogs are one of the most valuable assets to a team locating a missing person. Our canine friends are particularly adept at covering vast distances in the wilderness and climbing over the rubble of collapsed buildings to track the scent of a person.

Training starts when they are puppies, since they learn by air scent – a natural skill to them as they can pick up the smell of the 40,000 skin cells a human sheds every minute. [illegible], one of the SAR volunteers in Kent, explains: "They're trained exactly the same as avalanche rescue dogs. We train the dog's nose to find the scent as if there is a human somewhere, they can locate it."

The dogs are trained using treats when they successfully find a person and always work in a pair with their handler.

[illegible]

The Airbus Super Puma SAR is often relied on in Iceland, where conditions make on-foot searches difficult

Rescuers in Alaska protect a victim from the downwash of a landing helicopter

Mountain climbers are particularly at risk of needing SAR assistance as injuries are common and they are usually unable to [illegible] help

MARITIME RESCUE

Catastrophe at sea brings a whole new set of challenges to SAR teams

The ocean is unpredictable even for the most seasoned sailors; with few navigational landmarks, limited communication with the mainland and erratic weather changes, it's easy for seafarers to find themselves in danger. Fortunately, experienced maritime teams are ready to come to the rescue. The training is intense, but with thousands of people going missing at sea every year, it is a vital service.

The Royal National Lifeboat Institution (RNLI) is a UK charity organisation dedicated to saving lives at sea. Their 24-hour lifeboat search and rescue service has saved over 140,000 people since its foundation in 1824 and prides itself on the courage of its volunteers, who work tirelessly to keep people safe and return them to dry land. Whether it is rescuing the passengers of sinking ships, pulling yachts with engine failure back to shore or searching for people dragged out into the ocean due to strong currents, the RNLI average 24 call-outs every day.

The volunteer teams around the UK are provided with state-of-the-art equipment and first-class training, during which they learn sea safety and survival techniques and how to operate radar, electronic navigation equipment and rescue boats. The RNLI College in Poole is home to a unique wave tank that simulates violent weather. The special effects are incredibly realistic. A powerful wind machine creates gales, while sound and lighting systems recreate thunderclaps and lightning. This means the teams can practise capsizing drills and sea survival, so when they first experience an emergency they will deal with it confidently.

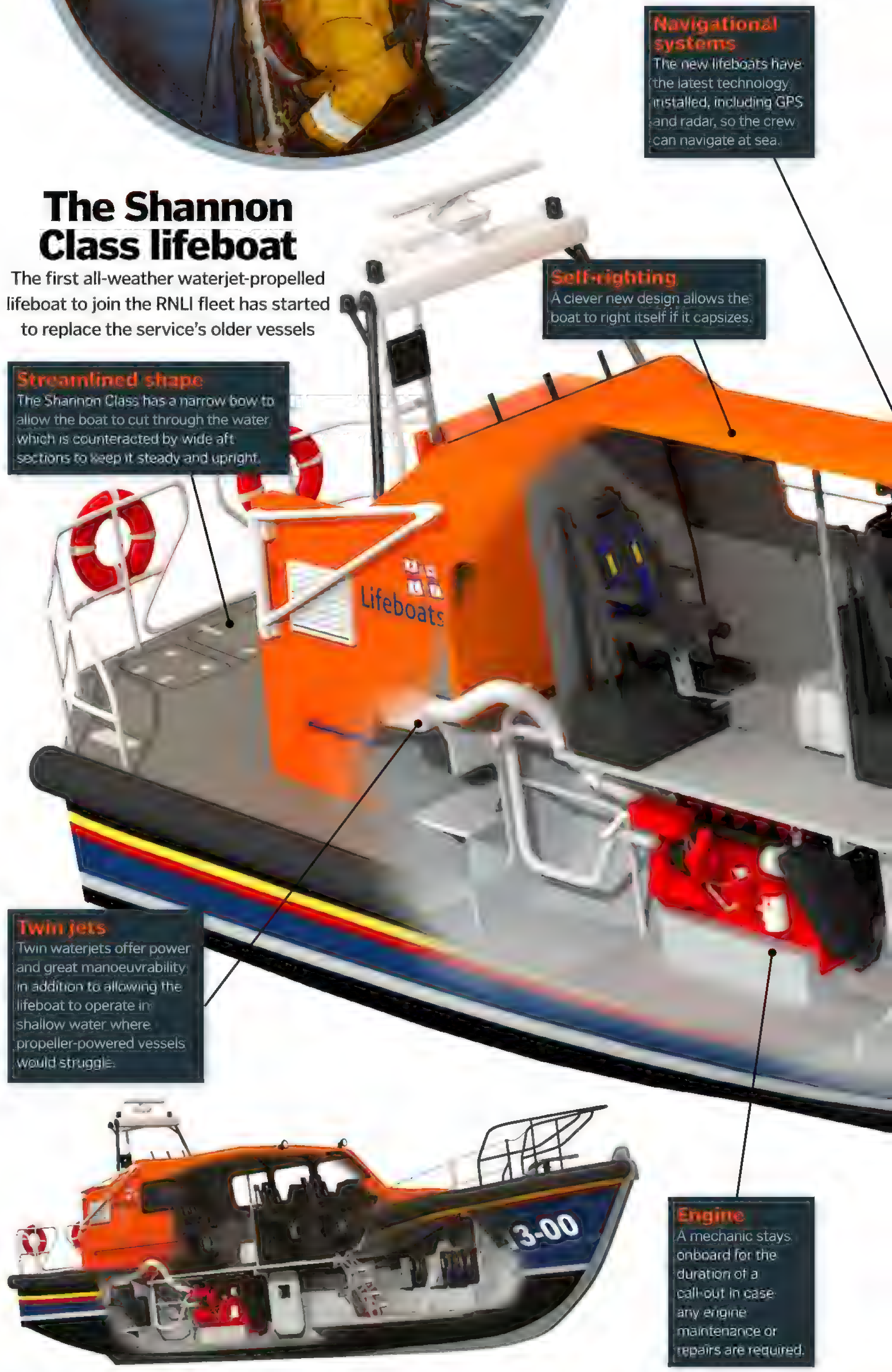
According to Andy Buck, an RNLI volunteer, the biggest problem in a search and rescue can be identifying someone's location. "It can be difficult because there are no landmarks at sea – it's just water, so people don't always know where they are located. But we can triangulate positions of a distress call while we're on the boat when someone calls on the radio."

When emergencies are closer to the shoreline it falls to Her Majesty's Coastguard – a branch of the Maritime and Coastguard Agency – to take action. The two organisations work together closely to ensure the safety of those in UK waters.

Training drills in the ocean are essential for crew so they can respond efficiently when there is a real casualty

The Shannon Class lifeboat

The first all-weather waterjet-propelled lifeboat to join the RNLI fleet has started to replace the service's older vessels



The new Shannon Class RNLI lifeboats are faster and better equipped than the older models they are replacing

Interview with an RNLI volunteer

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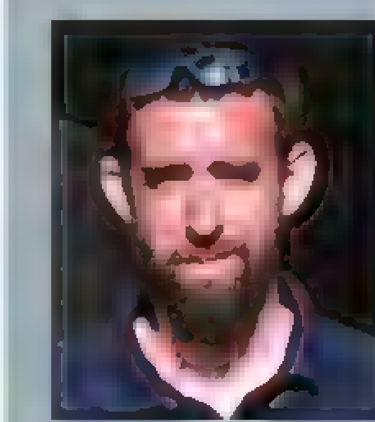

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Head to howitworksdaily.com to read the interviews in full

"With courage, nothing is impossible"
Sir William Hillary (1771-1847)
Founder of the RNLI

How helicopters fly

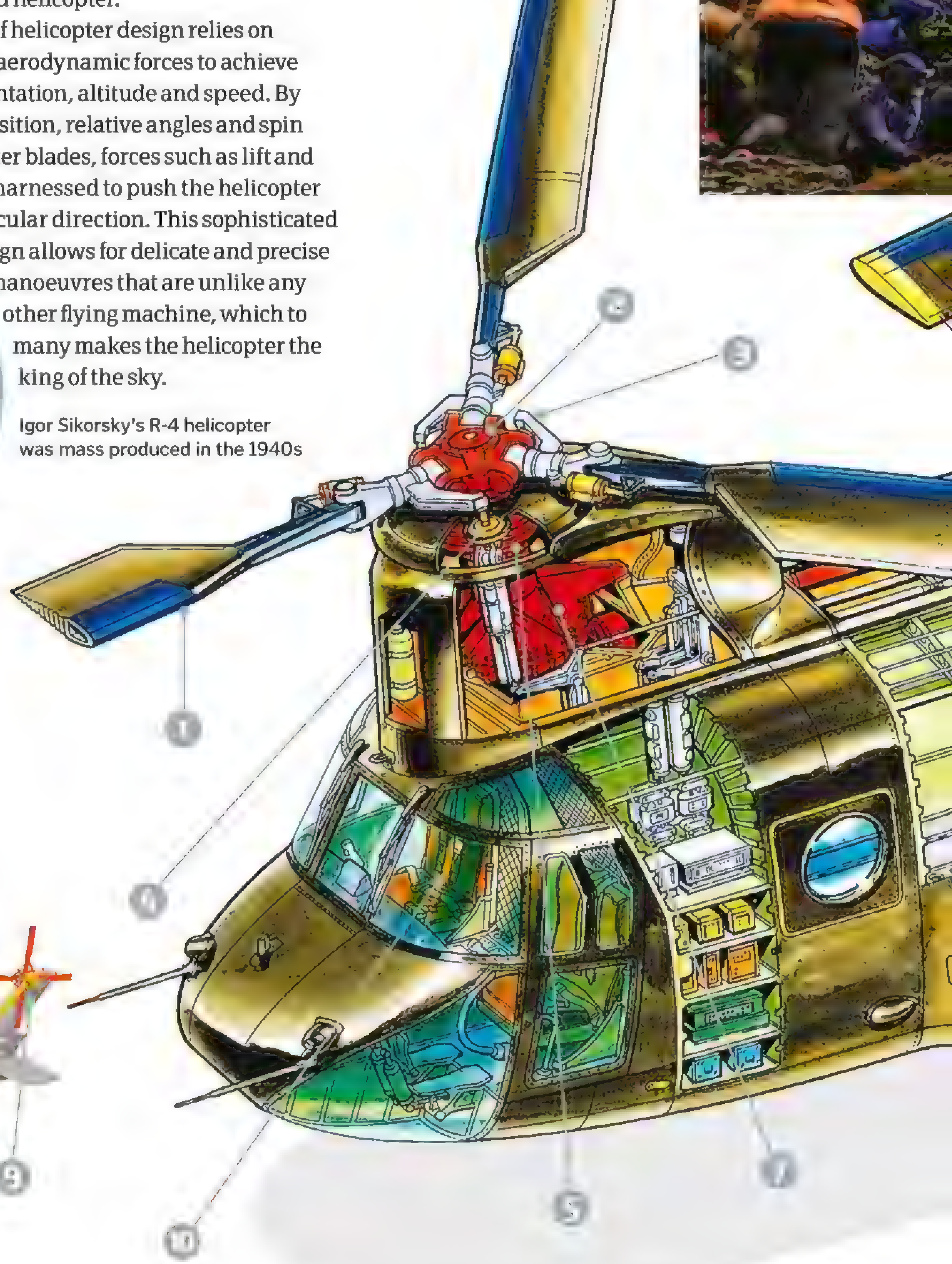
Discover the science behind helicopter flight and what makes them our most inventive flying machine

Helicopters are incredible vehicles. They're able to take off and land just about anywhere, and once in the air they can hover, swivel, yaw, ascend, descend and zoom off in any direction with ease. This amazing airborne control makes them perfectly suited to rescuing people at sea and on land, fighting fires and performing combat manoeuvres. From the ambulance service to the air force to the transport industry, helicopters have become a major asset by reaching the places that no other machine can, and they do it in style.

The concept of a helicopter is over 1,500 years old, and somewhat bizarrely finds its origin as a Chinese toy. Children were instructed to attach feathers to the end of a stick and spin it quickly, which would create enough lift to raise the toy into the air. Leonardo da Vinci would later famously theorise on his own 'aerial screw' during the Italian Renaissance, but it was an 18th-century Russian engineer by the name of Mikhail Lomonosov who would actually assemble a working, spring-powered model of coaxial helicopter blades. About 180 years after him a fellow countryman by the name of Igor Sikorsky would graduate from models of his own to the real thing by patenting and flying in his very own flying machine. Sikorsky's pioneering R-4 would go on to become the world's first mass-produced helicopter.

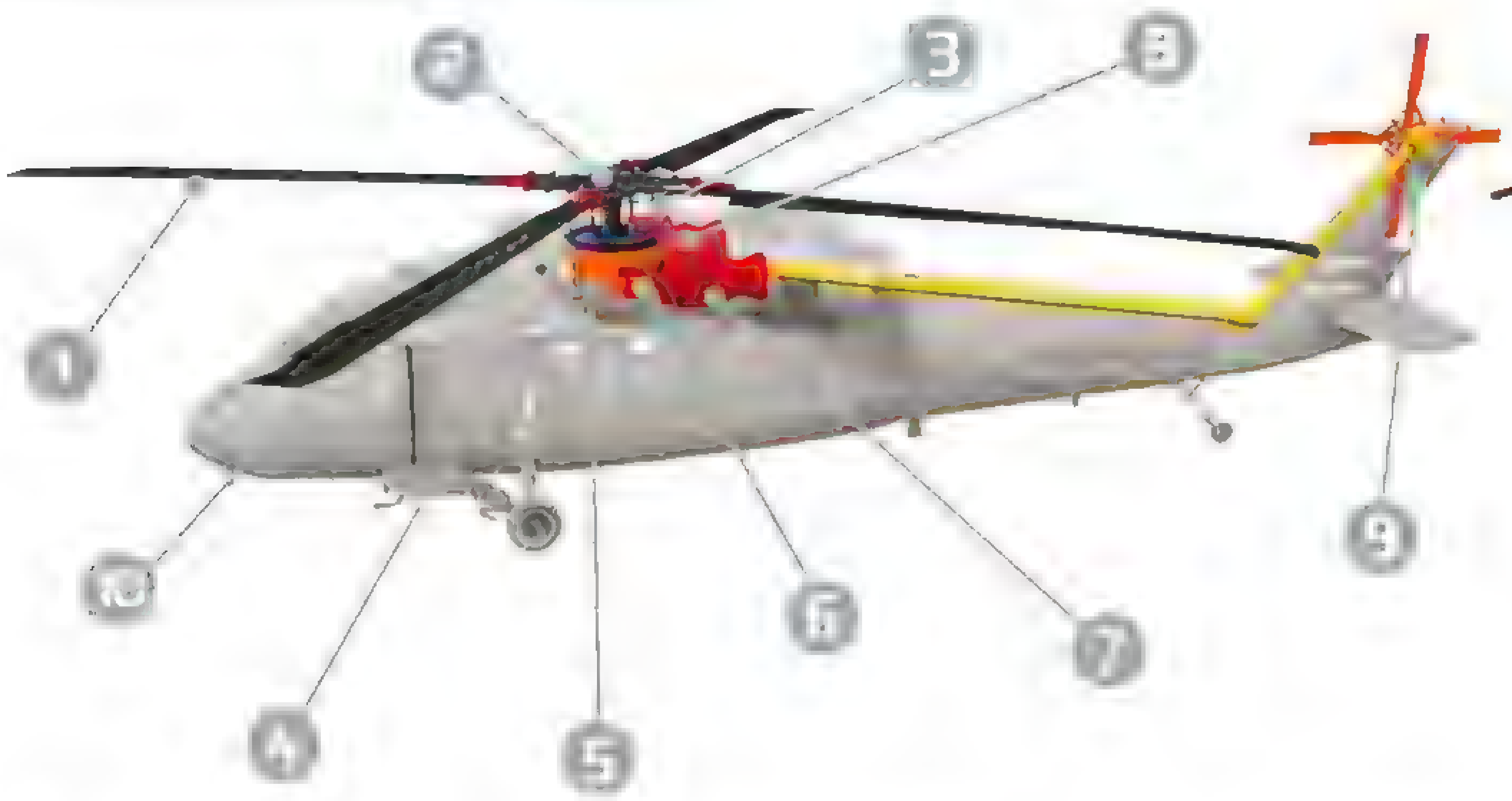
The genius of helicopter design relies on manipulating aerodynamic forces to achieve change in orientation, altitude and speed. By altering the position, relative angles and spin rate of helicopter blades, forces such as lift and torque can be harnessed to push the helicopter in a particular direction. This sophisticated design allows for delicate and precise manoeuvres that are unlike any other flying machine, which to many makes the helicopter the king of the sky.

Igor Sikorsky's R-4 helicopter was mass produced in the 1940s



To the skies

The mechanics that make the helicopter the most versatile machine in the air



1 Main rotor blade
Like an airplane, these blades are shaped as an aerofoil, which narrow to one side and create lift when rapidly rotated.

2 Rotating hinge
Each blade is independently affixed to the rotating mast by a feathering hinge, which allows the blade to swivel.

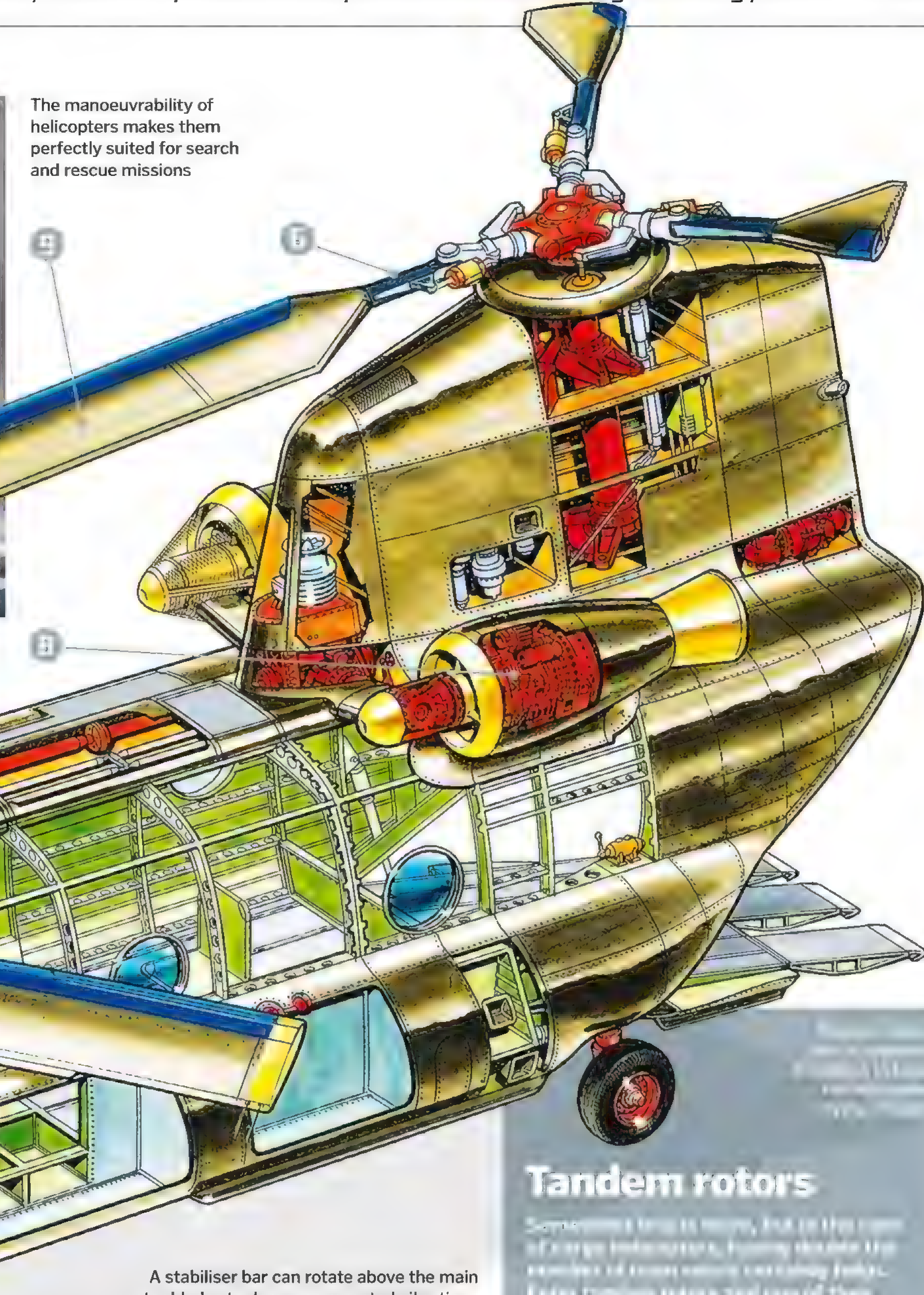
3 Control rods
Pitch links connect each blade to the swash plate below. When tilted, the raised section of the plate forces the rod to swivel its blade, increasing its pitch.

4 Upper swash plate
The upper plate shares the lower plate's tilt but can spin freely, allowing it to be attached to the control rods.

5 Lower swash plate
Steering controls from the cockpit are relayed to this lower plate, which tilts to influence the upper plate.

6 Changing pitch
Increasing a blade's pitch (how vertical it is) will increase its lift. Increased lift at one location (e.g. the front) will change the helicopter's direction.

The manoeuvrability of helicopters makes them perfectly suited for search and rescue missions



A stabiliser bar can rotate above the main rotor blades to dampen unwanted vibrations

Tandem rotors

[illegible] acting forces. The risk of collision between the opposite blades is also [illegible] rotors to the same transmission.

7 Gearbox
Both the main rotor and tail rotor are connected to a gearbox via a driveshaft.

8 Engine
Helicopters can use piston engines like those used in cars but more commonly now use gas turbines akin to jet engines.

9 Tail rotor
As the main rotor rapidly spins the helicopter body will want to spin in the opposite direction. Tail rotors provide torque that negates this force, keeping the body straight.

10 Cockpit
Helicopter pilots must simultaneously control pitch and the throttle to keep the vehicle moving in the right direction.

ROCKET TRAVEL

Come aboard and find out why rockets are set to replace commercial aircraft

Words by James Horton

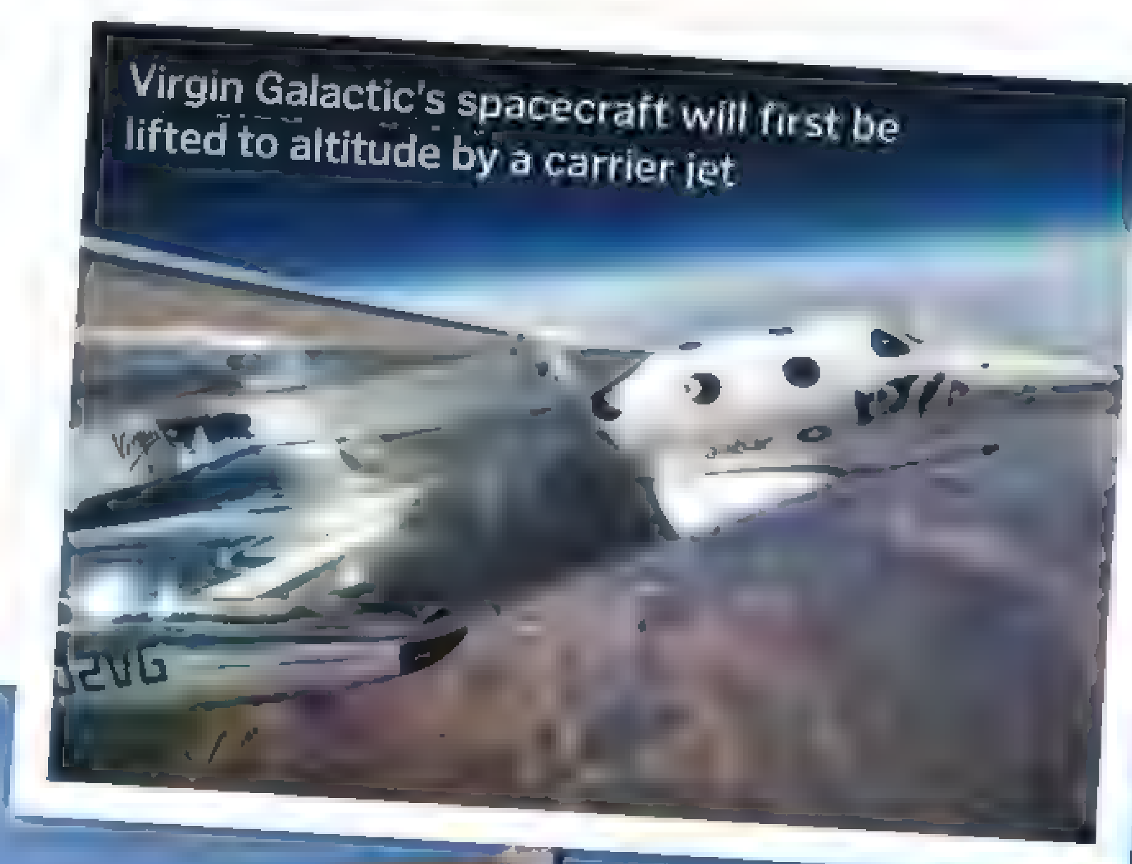
"Anywhere in the world, in less than an hour." Elon Musk and his company SpaceX may have already revolutionised the way we utilise rocketry, but now they seek to use their technology to take us to Mars, the Moon, and even from city to city. And, quite amazingly, the price of enjoying this last application could cost the same as an economy airline ticket.

Known as the 'Big Falcon Rocket', or more simply as the BFR, SpaceX's upcoming spacecraft is set to satisfy all of our space-faring needs in one neat package. It will build upon the staggering success of their previous two rocket designs: the Falcon 9, which at the time of writing has successfully completed nine launches, and the Falcon Heavy, which first took to the skies in February 2018. These rockets have demonstrated for the first time in our history that not only can you land the first stage of a rocket booster on the ground safely, but you can reuse it. It is from this milestone that the BFR's goal to not only take people off-world but also shuttle them around it becomes viable and immensely promising.

Standing at a mammoth 106 metres in total, the BFR will be composed of two major stages: a 58-metre-tall booster used to lift the vehicle into orbit, and a ship mounted atop the booster. This front portion will be equipped with 1,100 tons of additional fuel and boast a large, pressurised cabin for its city-to-city launches. This will give the BFR everything it will need to send its customers into sub-orbit and speeding around the globe. Here, passengers will be treated to not only arriving at their destination ludicrously quickly but also to the majestic views of our planet that so far only a few lucky individuals have seen. Surely those sights alone will justify the cost of the ticket, with the fast arrival time becoming a rather big cherry on top.

It should be noted that SpaceX is not alone in its lofty ambitions. Not so far away another private company, Virgin Galactic, are creeping ever closer to their own sub-orbital flights. They plan for these to initially be sold for recreation and research but also harbour long-term goals of trans-continental transport. Unlike the BFR, their two-component system involves a jet-powered carrier aircraft and an attached rocket-powered ship, which releases from the carrier craft and launches towards space once at altitude. Across the Atlantic, UK company Reaction Engines also dreams of a vehicle that can soar from the runway to space as one whole unit. Their pioneering air-breathing SABRE engine aims to be an alternative to pure rocket power or jet engine/rocket hybrids like that of Virgin Galactic. Although this technology isn't currently as tangible as SpaceX's, it would almost certainly have incredible transport applications if it were to come to fruition.

In 1873, Jules Verne published a story about a man's attempt to race around the world in 80 days. It is a tale of great adventure, but one that pales in comparison to the journey that we have taken as a species in the years since its publication. We have ascended from the ground to the air and from the air to the realm beyond. In fact, such is the staggering progress of our technological prowess over these years that by 2023 getting around the world in 80 minutes may not be quite quick enough.

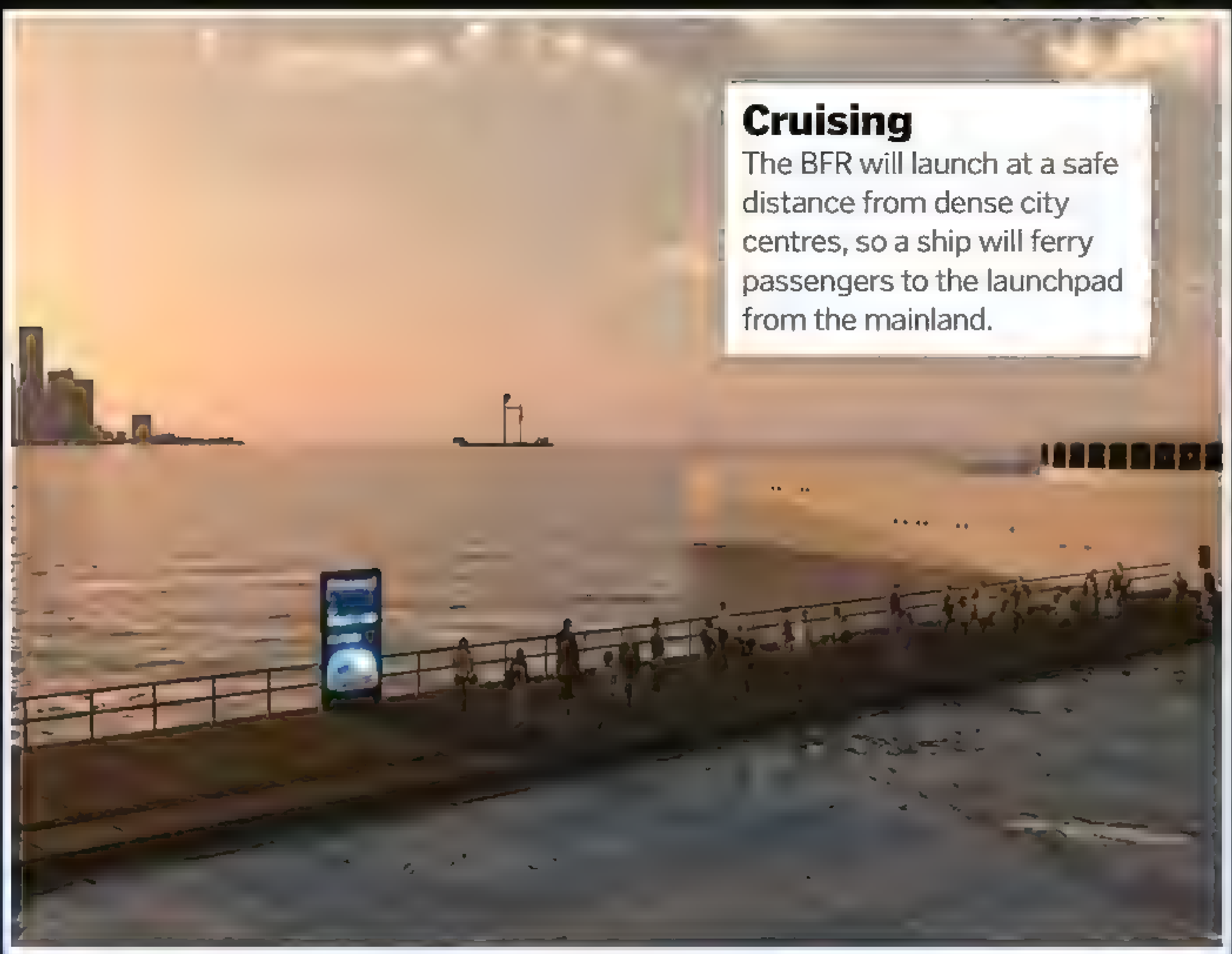

Virgin Galactic's spacecraft will first be lifted to altitude by a carrier jet


Rocket travel would revolutionise global travel by dramatically cutting down journey times

Same goal, different approach

City to city on the BFR

Hop aboard the Big Falcon Rocket and travel to anywhere in the world in under 60 minutes



Cruising
The BFR will launch at a safe distance from dense city centres, so a ship will ferry passengers to the launchpad from the mainland.

All aboard
Passengers will ascend and enter the 106m-tall vehicle. Inside, the pressurised compartment will be larger than an A380's main deck.

Cool ascent
Thanks to the engine's liquid oxygen and liquid methane fuel, the launch will feel relatively smooth and comfortable.

Smooth journey
Above our planet's dense atmosphere, passengers will be free from turbulence. They can relax and enjoy the awe-inspiring views of Earth from above.

Detachment
Its job done, the booster rocket will detach. The ship's Raptor engines will then ignite, boosting the aircraft to top speeds of 27,000kph.

Lift-off
52,700kN of thrust, provided by the booster rocket, will be used to lift the spacecraft out of the atmosphere.

Reusable
The first stage booster will be able to land autonomously. It will then be reserviced, refuelled and reused.

DID YOU KNOW? *For longer journeys, such as those headed towards Mars, the BFR will be refuelled during orbit*

Journey times comparison

ROUTE	DISTANCE	FLIGHT TIME	BFR TIME
LA to New York	3,983km	5 hours, 25 min	25 min
Bangkok to Dubai	4,909km	6 hours, 25 min	27 min
Tokyo to Singapore	5,350km	7 hours, 10 min	28 min
London to New York	5,555km	7 hours, 55 min	29 min
New York to Paris	5,849km	7 hours, 40 min	30 min
Sydney to Singapore	6,288km	8 hours, 20 min	31 min
LA to London	8,781km	10 hours, 30 min	32 min
London to Hong Kong	9,648km	11 hours, 50 min	34 min
Sydney to Johannesburg	11,078km	13 hours, 35 min	37 min
Doha to Auckland	14,548km	17 hours, 43 min	45 min
Sydney to Zurich	16,576km	20 hours, 08 min	50 min
Rio de Janeiro to Hong Kong	17,709km	21 hours, 28 min	53 min

Sub-orbital transit
Unlike jet aircraft, the BFR will breach the atmosphere, continue its arc while in orbit and make an atmospheric re-entry.

Weightlessness
After the ship's burn is complete, passengers will experience the feeling of weightlessness for a brief period as the aircraft coasts through space.

Comparable price
As the mechanical parts of BFR will be wholly reusable and its fuel incredibly cheap, passengers will pay similar prices to an economy airline ticket.

Re-entry
As the ship adjusts its orientation to slow its descent, the increased G-forces will cause passengers to feel several times heavier than usual.

Soft landing
Two engines will fire to bring the BFR to a safe and controlled stop at its destination.

"By 2023, getting around the world in 80 minutes may not be quite quick enough"

How they crash-test cars

Welcome to Ford's state-of-the-art car safety testing facility

Test dummies come in all shapes and sizes, simulating different body types and ages of passengers

In 2018, car manufacturer Ford opened the doors of its new €15.5-million (around £14-million / $17-million) testing facility in Cologne, Germany. This facility has the capacity to carry out up to four crash tests per day, and the new sled-test system is by far one of the most impressive pieces of technology Ford is using to test car passenger safety.

Sled tests are a way to reproduce a high-speed collision in a controlled environment. The car compartment that typically holds passengers is mounted on a trackway, then a connected hydraulically powered propulsion system launches the compartment backwards along the track. In the case of Ford's new system, that's a propulsion force equivalent to 250 tons, 80 times the force of gravity experienced in typical road collisions.

Within the compartment are high-tech dummies equipped with around 70 sensors including accelerometers, each recording impact data for engineers to later analyse. Accelerometers record the speed and direction the various sites on the dummies' bodies travel during a crash. This information is then used to develop the interior features of the car, such as seat belts and airbags. At different points of the dummies' faces strips of paint are applied, which during the simulated crash transfer onto deployed airbags. This provides an imprint on the deployed bag and information about their effectiveness.

"Full-scale crash tests give us a wealth of information but they take longer to set up," explained Stephan Knack, head of the Ford Crash Test facility. "Virtual crash tests are fast but [they are] not yet as reliable as the real thing. Our new sled test bridges the gap between the real and the virtual worlds, so that we can deliver improvements faster, resulting in safer vehicles."

Primed to crash
A replica passenger compartment is attached to a hydraulically powered propulsion system.

Autonomous reactions

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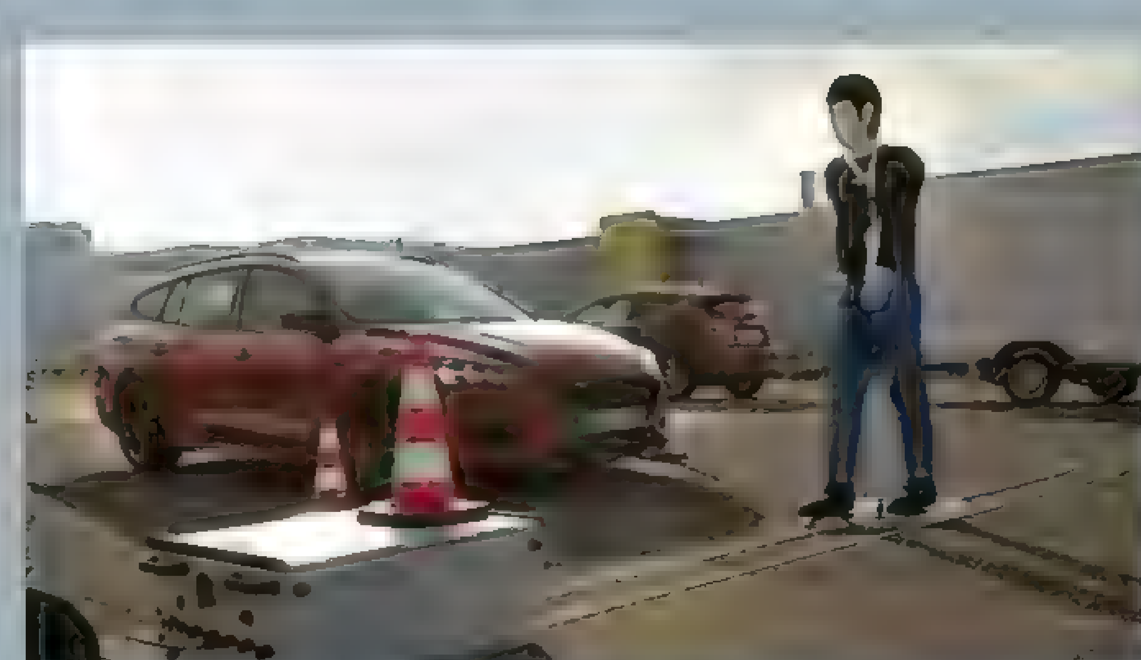

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The dummies that save lives

Sled tests are used to test the physical effects of a high-speed collision on passengers' bodies using high-tech dummies

Big impact
Experiencing an acceleration of around 80 times the force of gravity, crash dummies have inbuilt sensors and accelerometers to record their movements during the test.

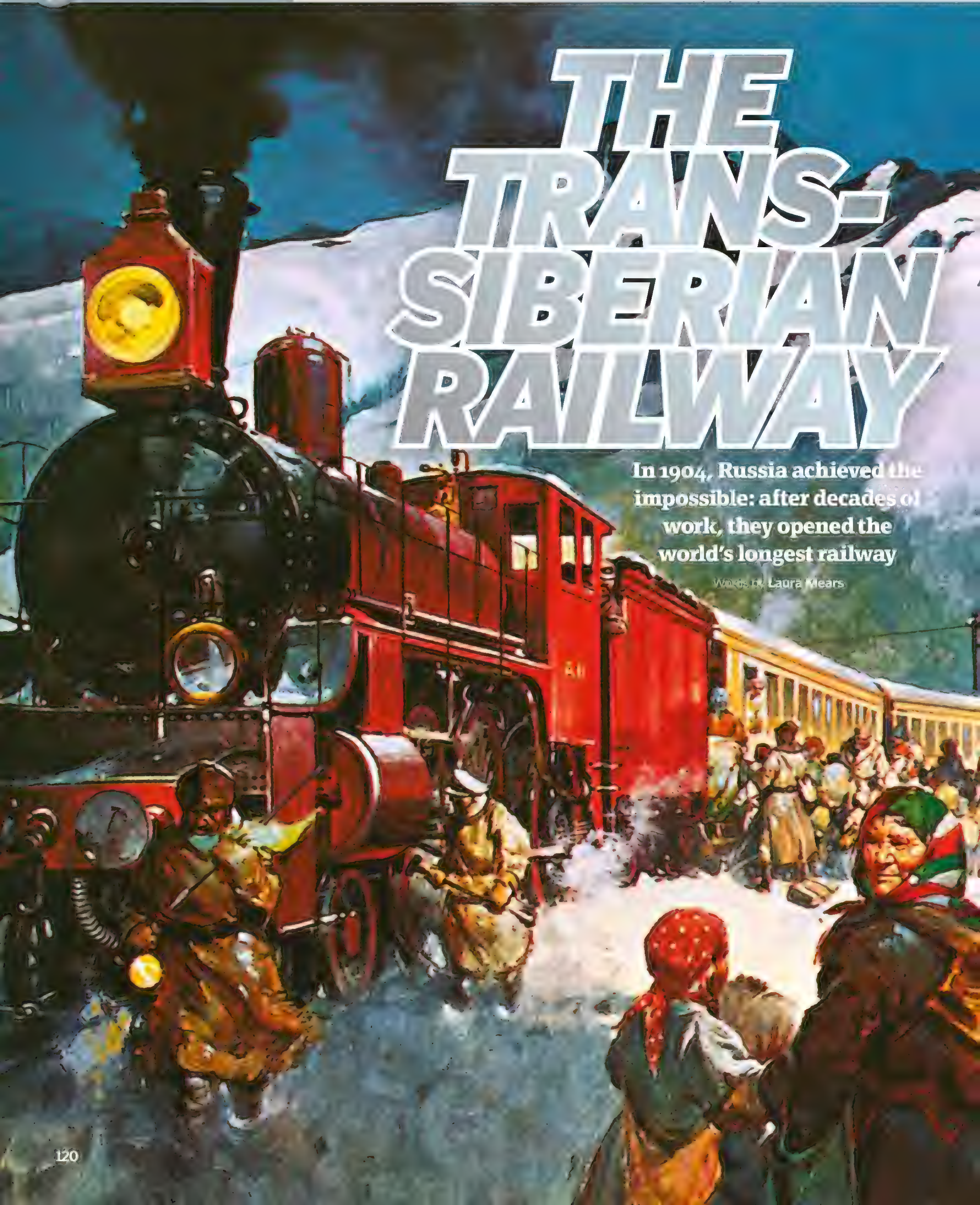
Lights, camera
High-powered lights surround the sled test to ensure the clarity of the images from the high-speed cameras.

Catching the crash
High-speed cameras record the sled test at a rate of 1,000 frames per second, allowing engineers to evaluate the airbag and seat belt timings.

Head-on collision

Despite its many advantages, what the sled test can't do is test the effects of a crash upon the entire car. This is where the full-scale head-on crash test comes in. While these tests are another way to study the effects on the passengers during a crash, a head-on collision test measures the effect a crash can have on the car itself. Having driven the car at a speed of 50 kilometres per hour, the front of the new Ford Focus crumples as it collides with a reinforced wall. During the collision cameras are used to capture the impact frame by frame at around 1,000 frames per second.

© Ford



THE TRANS-SIBERIAN RAILWAY

In 1904, Russia achieved the impossible: after decades of work, they opened the world's longest railway

Words by Laura Mears

Built by hand through one of the harshest environments on Earth, the Trans-Siberian Railway stretches 9,258 kilometres from Moscow to Vladivostok. Hundreds of men died laying the tracks, and the project sent Russia to war with Japan, but it finally linked the West to the East.

Work on the line began when Russia was still under the rule of the tsars. The capital of Alexander III's disjointed empire lay in the west, separated from the eastern border by desolate snow forests. The only way to cross was by wagon or along waterways that turned to ice during the winter. Russia's eastern ports froze over when the snow hit, and messages sent by telegram regularly went missing. Inside the country there was talk of revolution. Outside, Russia's eastern frontier was vulnerable to attack. They desperately needed a weatherproof transport network to unite the population.

Following in the footsteps of North America, Minister of Transport Count Sergei Witte suggested trains. A Trans-Siberian Railway could do for Siberia what the First Transcontinental Railroad did for the Wild West. However, the line would need to cover almost three times the distance. Russia didn't have America's resources – they lacked the money, the workforce and the experience. What's more, the tracks would have to pass through some of the world's roughest terrain. The railway would sit on permafrost, frozen for months at a time and liable to melt during summer. The tracks would cross rivers, travel around the world's largest freshwater lake and slice through mountains.

If they managed to pull it off, the rewards could be huge. The population in Siberia was thin and industry underdeveloped. But this inaccessible landscape, blanketed in snow for much of the year, contained most of Russia's resources. Siberia hides oil, coal, gas and diamonds. The Ural Mountains have magnetite, bauxite, gold, platinum, asbestos, talc, amethyst and topaz, and between the precious rocks there are fertile plains. Better transport links promised to make the country millions. Russia's poor would have access to new jobs. New markets would open with Japan, China and Korea, and exports could travel easily from Asia to Europe. Russia could become the gateway to the East.

Russia poured the equivalent of 50 million US dollars into the project, financing the new railway with loans and taxes. The treasury courted rich European investors, promising lavish trips to Asia. They made a deal with China, agreeing to extend the railway line into Manchuria, and they printed more money, risking the financial security of the empire.

The tsar wanted the project finished within ten years, but the climate in Siberia made working during winter impossible. To save time, they planned to lay the track in six simultaneous sections. To cut costs, they would build a single iron rail instead of a double steel track, and bridges would be wood rather than metal or stone. There would be fewer sleepers to pin the track together, and they would build everything by hand – no machines or dynamite.

Gathering the men to build the track was challenging. Even with the promise of free accommodation, people were reluctant to move to Siberia from Russia's cities. Siberian natives disliked the idea of the railway and refused to work. In the end, men from China, Persia and Turkey made up much of the workforce, along with Russian prisoners and exiles. The convicts exchanged work for time off their sentences and spent their nights chained to wheelbarrows. For complicated tunnels and bridges, stonemasons

The Soviet Union upgraded the railway, replacing the iron tracks with two strong steel lines

Russia drafted construction workers from China, Turkey and Persia

The railway that started a war

The Trans-Siberian Railway extended Russia's reach into the East. A deal with China took the line into Manchuria, and in return Russia secured a lease for the ice-free Chinese naval base at Port Arthur. By 1904, with construction on the main line progressing, Russia started sending [illegible], but not everyone welcomed their arrival. Japan also had designs on Manchuria and the Korean Peninsula. In an effort to halt Russia's unwelcome expansion, they attacked Port Arthur in 1904.

With the Siberian portions of the railway still unfinished, Russia struggled to respond. Troops became stranded at Lake Baikal, unable to cross the frozen waters. After multiple defeats, Tsar Nicholas II eventually backed down. The Treaty of Portsmouth restored peace to the region, returning Manchuria to China and giving the South Manchuria Railway to Japan.

[illegible]

were drafted in from Italy, a nation over 6,142 kilometres away.

More than 15,000 people worked on the project, toiling from dawn until dusk, which in the high latitudes of Siberia lasted deep into the night. The men used wooden shovels, rakes and pickaxes, hefting soil and stone with their hands and relying on horses to take the heaviest loads, which were eaten when they became too weak.

Poor planning stalled the project at every turn. Engineers contracted to survey the ground failed to map every stream, river and hill, and they didn't account for the meltwater that raced over the landscape in the spring. Flooding created swamps, anthrax spread through the animals and people fell to fevers transmitted by mosquitoes. Workers eventually resorted to wearing nets to keep the insects at bay.

Together they soldiered on, crossing rivers and bogs, sometimes working waist-deep in water. They cut paths through inaccessible forests and built lines in perilous valleys. Work only stopped in winter when the weather became too harsh.

The most challenging section of track was at Lake Baikal. Bounded by mountains and coated with ice in the winter, it was all but inaccessible. The original plan was to use a boat to transport the carriages. Made in England, the Baikal Ferry had a reinforced steel hull and a propeller to cut through the ice. It was so enormous that they had to break it into chunks to get it to Siberia.

When it finally arrived, it wasn't up to the job. During the warmer months massive storms tossed the ferry off course and fog obscured the view. In the winter the ice was up to 2.7 metres thick and the propeller couldn't cut through.

Finding a way to cross the lake became urgent when Japan attacked Port Arthur in 1904, so they tried laying tracks over the ice – the first train fell straight through. They only solution was to go around, carving 38 tunnels through the granite cliffs on the shores.

As the project neared completion cost-cutting took its toll. The railway started to break before it was even finished. The complicated route and rapid construction meant that failures were common. The trains crawled slowly along the rickety lines and were often delayed, overcrowded and undersupplied. But, though broken, the railway was a triumph.

Built by hand across one of the most hostile environments in the world, it was an incredible feat of human endurance. It offered new opportunities for Russia's poor, opening a corridor to a new life. Around 5 million immigrants moved to Siberia between 1891 and 1914. In the 1950s, the Soviet Union upgraded the railway, adding a second track, steel rails, new tunnels and new bridges. Now it's one of the strongest railway lines in the world.

The railway was officially completed in 1916, with some estimates putting its total cost at around $1 billion

Riding the rails

The Trans-Siberian Railway is studded with historic towns and cities

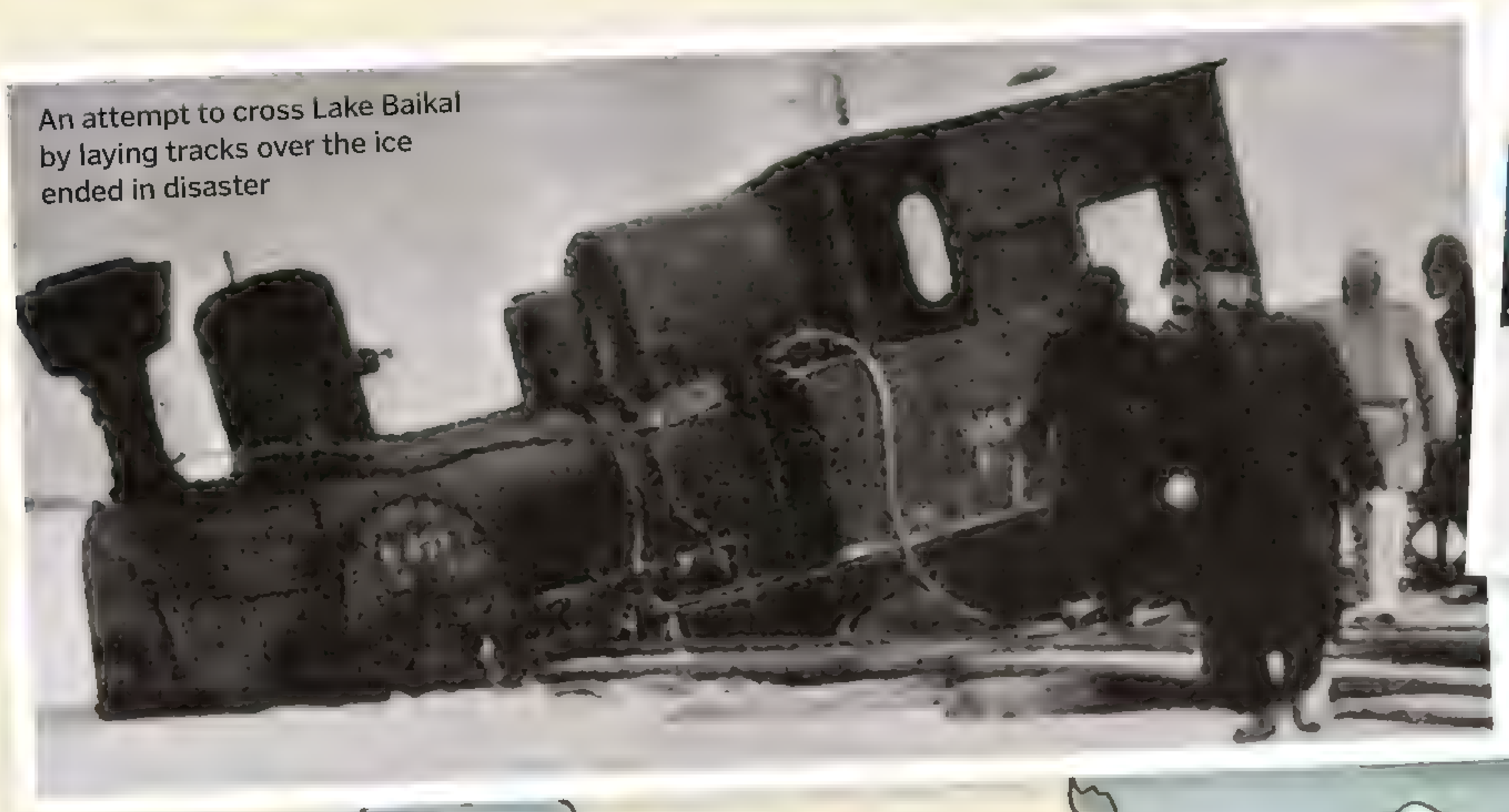
Yekaterinburg
Travellers to Yekaterinburg can visit the place where the Bolsheviks murdered Tsar Nicholas II and his family in 1918.

Moscow
Russia's capital is home to the Kremlin, Red Square and the world-famous Bolshoi Ballet.

Omsk
This concrete jungle lacks the architectural beauty of Russia's largest cities, but provides a welcome rest for rail travellers.

"Workers cut paths through inaccessible forests and built lines in perilous valleys"

Construction workers built the entire Trans-Siberian Railway by hand


An attempt to cross Lake Baikal by laying tracks over the ice ended in disaster


The Trans-Siberian Railway Network runs through one of the harshest environments on the planet

Krasnoyarsk
Home to the vast Stolby Nature Sanctuary, Krasnoyarsk is a popular stopover on the journey to Lake Baikal.

Baikal-Amur Mainline
Built on permafrost, this line provides an alternative route across northern Siberia.

Lake Baikal
This vast body of water is the oldest and deepest freshwater lake in the world.

Irkutsk
Eastern Siberia's main city, this is the place to stop if you want to visit Lake Baikal.

Vladivostok
This Pacific port is the final stop on the line, promising sandy beaches and beautiful architecture.

Trans-Mongolian
This line connects the Trans-Siberian Railway to Beijing via the Gobi Desert.

Trans-Manchurian
This historic stretch of railway passes through the Manchurian Plains of China.

The future of smart roads

One stretch of highway has been transformed into a test-bed for cutting-edge road technologies

Motorways around the world are being tested to the limit. With more vehicles on the roads than ever before and new technologies changing the way they operate, infrastructure must adapt to support the increased load and evolve with our advanced cars. Whether they're electric or autonomous, or they run on biofuel or solar power, roads and vehicles need to evolve together in order to pave the way for a sustainable future.

One project pioneering this idea is The Ray in Troup County, Georgia, US. Built on a 29-kilometre section of Interstate 85, The Ray is a working test site for the new advanced systems that will deliver the smart roads of tomorrow.

The Ray is a 29km section of the Interstate 85 highway in Georgia

The Ray

What technologies can be found along this hi-tech highway?

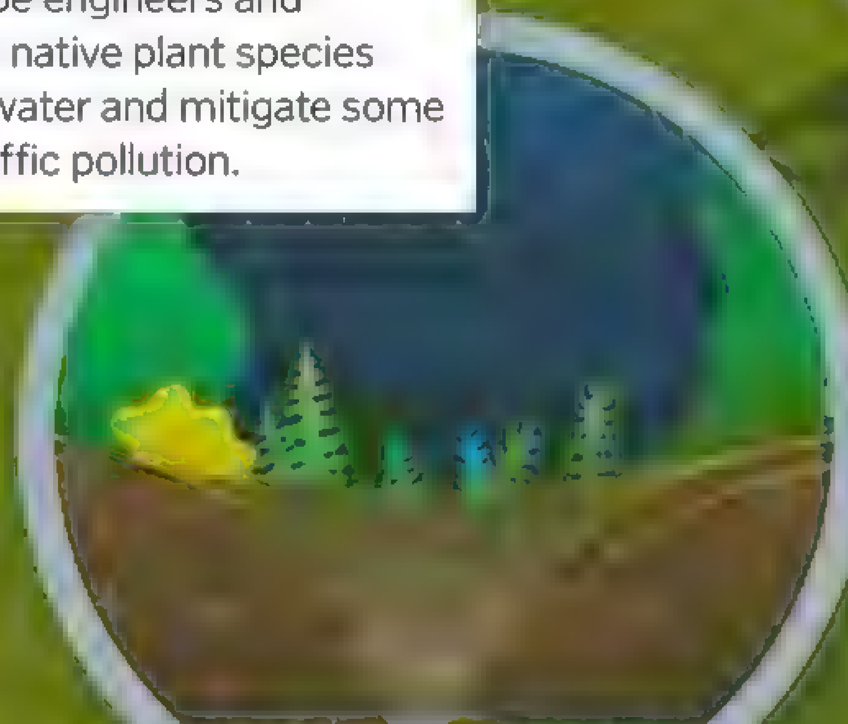
Farming in the hard shoulder

The key to innovative smart road designs is to utilise space as much as possible. The right-of-way (the land around the highway) can double up as farm land. Crops here can clean water runoff and capture carbon.

Kernza wheatgrass was planted in a 93m² plot by The Ray in October 2017. It will be harvested as a fibre source for products like paper towels

Bioswales

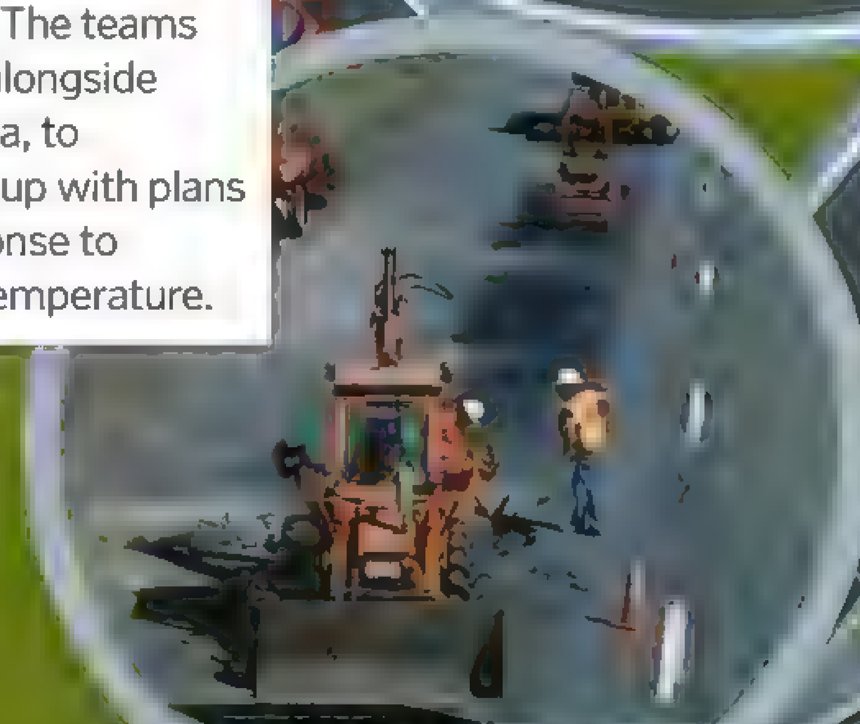
These shallow drainage ditches are planted with vegetation or filled with compost to slow water that runs off from the road as well as capture particles of pollutants such as rubber and oil. The Georgia Department of Transportation has worked with a number of landscape engineers and ecologists to select native plant species that can clean the water and mitigate some of the effects of traffic pollution.



The bioswales will help to control and clean the highway's water runoff during rainstorms

Climate modelling

The team behind The Ray have teamed up with Resilient Analytics to assess the vulnerability of this section of highway to the effects of climate change. The teams can analyse this information, alongside case studies and historical data, to determine the risks and come up with plans to reduce the damage in response to changes in precipitation and temperature.



Data from the project can help the team adapt to the challenges of a changing climate, thereby helping them to

The future

Other ideas in the pipeline at The Ray include smart studs, which improve on current road reflectors. These solar-powered lights would be able to illuminate in different colours to convey different messages to drivers, such as upcoming junctions or dangerous conditions ahead.

Another technology being considered is electric charging lanes, which would charge a car's battery as it drives along by electromagnetic induction. This would mean that drivers could charge up without having to stop on their journeys. However, it would be an expensive project, so the team at The Ray have not yet made a final decision about pursuing this idea.

The Ray has been designed as a 'living laboratory' to test out these innovative technologies. Hopefully, many of the current and future trials will prove successful and we'll start to see smarter roads all over the world.

Solar-powered vehicle charging

A PV4EV (photovoltaic for electric vehicle) solar-powered charging station has been installed at the West Point Visitor Information Center. It can charge a typical electric car to 80 per cent of its total power in just 45 minutes. Eco-friendly charging stations like this will help support the growing number of electric cars on our roads, which currently lack sufficient infrastructure.

Pollinator garden

We need pollinators such as bees and bats to keep our ecosystems thriving and our crops healthy. Planting pollinator-friendly gardens is not only visually pleasing, it also provides these creatures with sources of pollen and nectar. The team working on The Ray installed a 650m² pollinator garden in 2016, helping to give local wildlife a boost.

Tyre safety check station

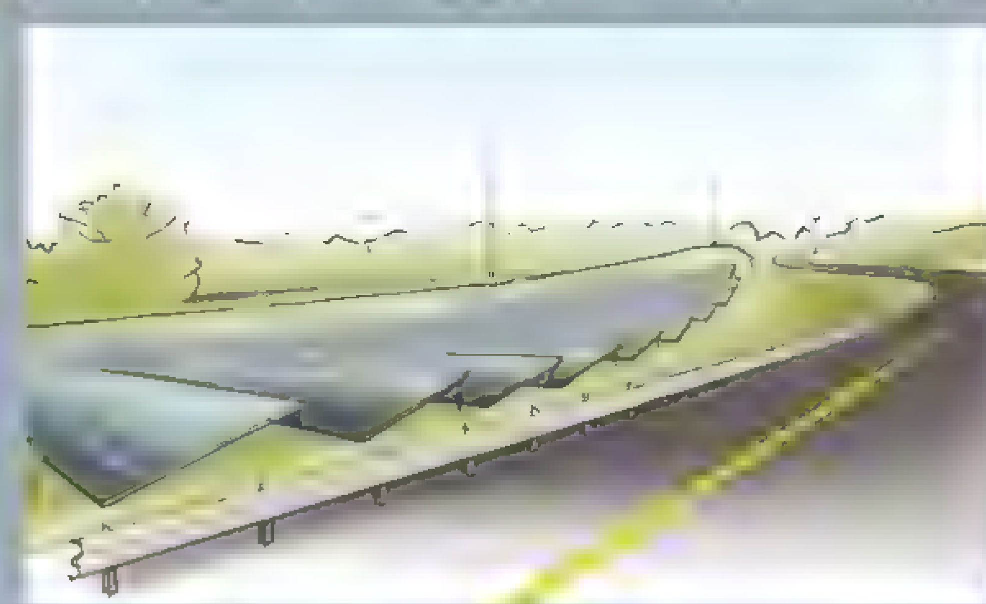
The clever roll-over WheelRight Tire Pressure Monitoring System on The Ray means drivers don't even need to stop to check their pressure manually. Instead, they just drive over a sensor in the road and the system sends them a text with information about the condition of their tyres.

Solar-paved highway

The Wattway is the result of five years of research and collaboration between transport infrastructure leaders Colas and the French National Institute for Solar Energy. A 50m² section of The Ray is paved with solar panels, providing a clean, renewable source of energy while still allowing traffic to pass.

Technology coming soon

Solar barriers



Right-of-way solar

Drones

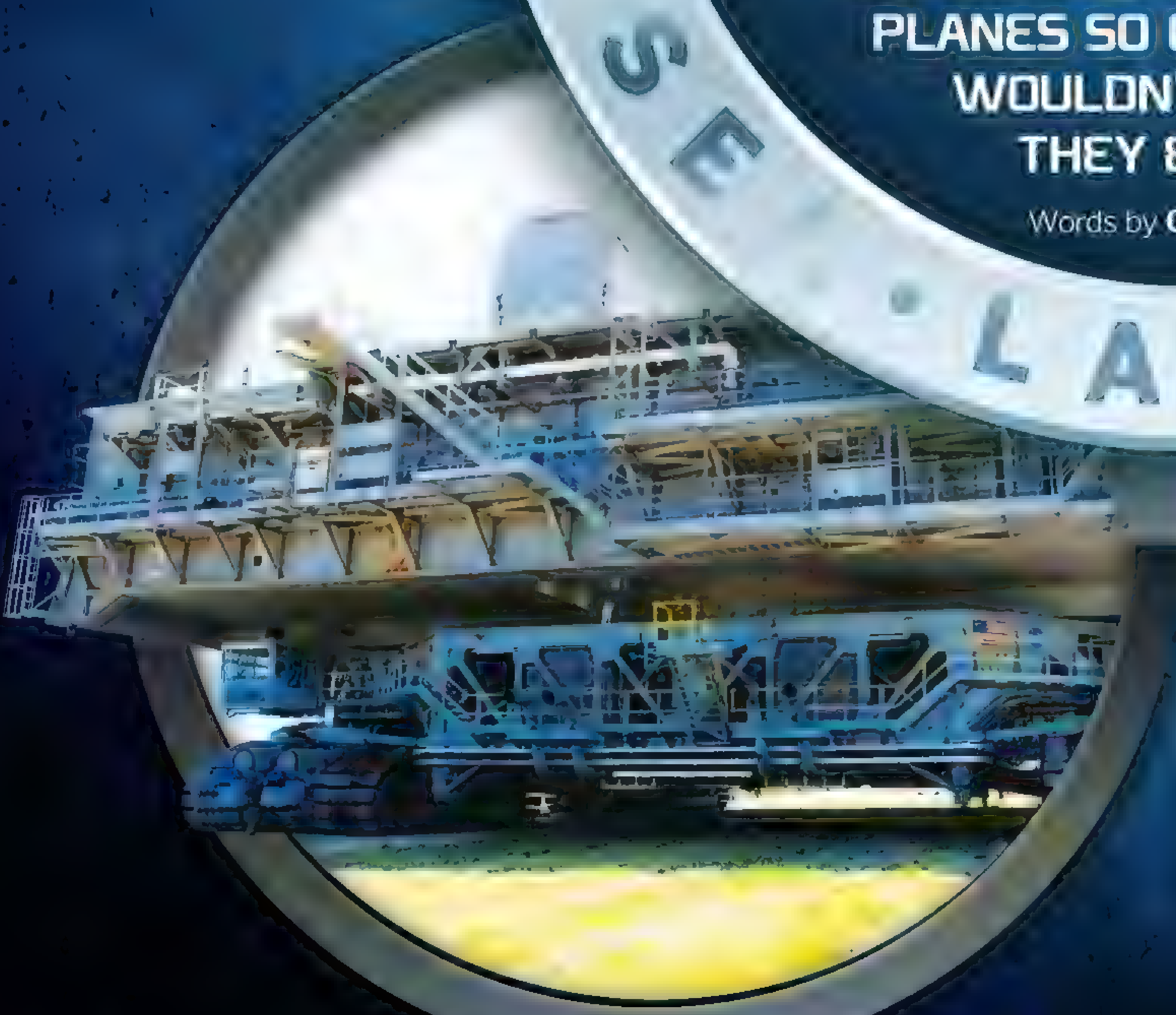
Rubber roads

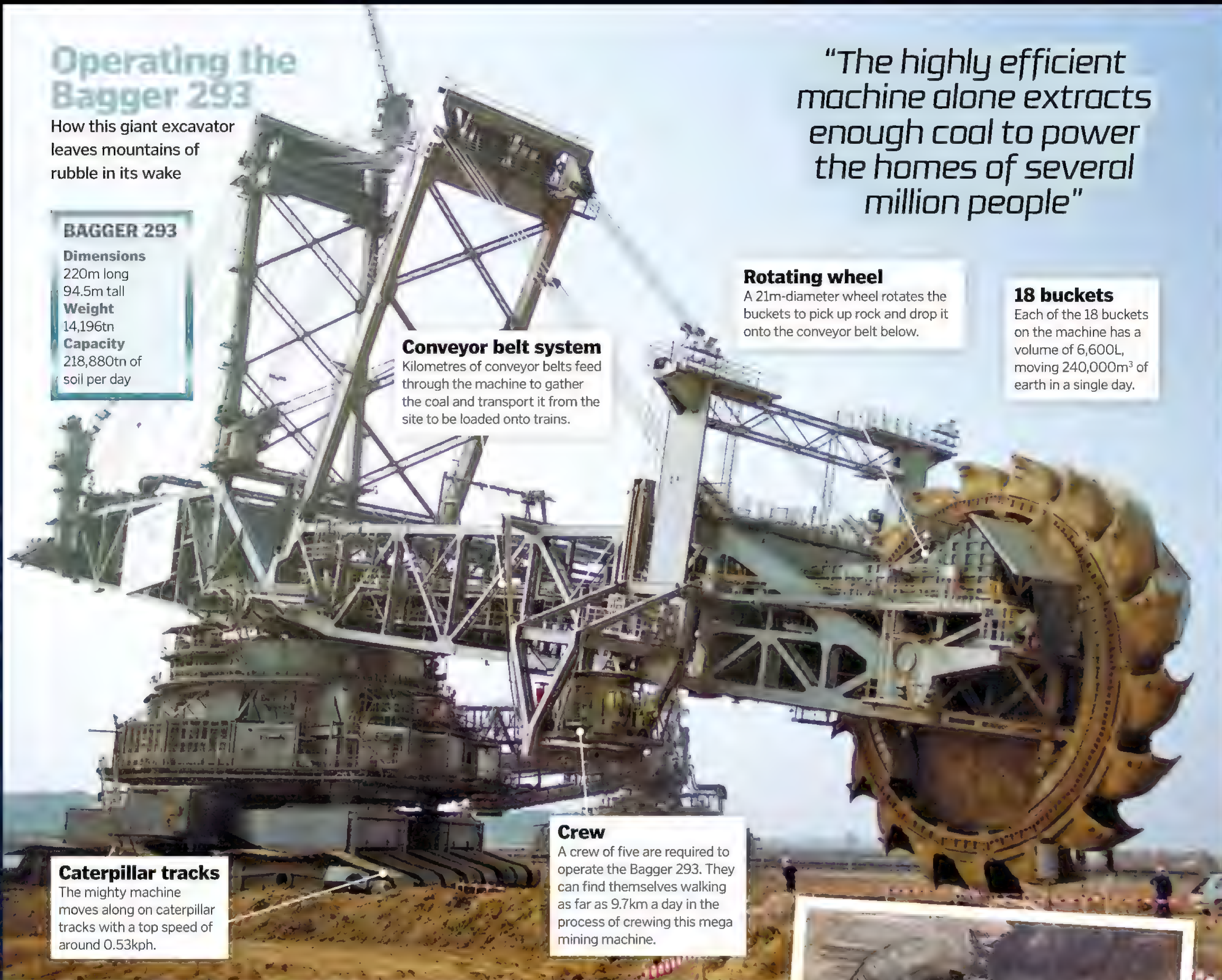
MEGA MACHINES

INSIDE THE MONSTER EARTH-MOVERS, FANTASTIC FLOATING CITIES AND FLYING SUPER-PLANES SO GIGANTIC YOU WOULDN'T BELIEVE THEY EXISTED

Words by **Charlie Evans**

SEA · LAND · AIR





PIT-MINING JUGGERNAUT

The Bagger 293 excavator is the world's largest land vehicle


The Bagger 293 is currently being used in a mine near Hambach, west Germany

Its incredible size and jagged-edged wheel makes the Bagger 293 look like something looming on the horizon of a post-apocalyptic nightmare. But what seems like an intimidating circular saw is actually composed of giant buckets designed to scoop earth as the wheel revolves and digs.

Baggers are a series of bucket-wheel excavators that operate in large, open mining pits. They are able to move thousands of tons of material every day, and when used with other machinery, such as conveyor belts and crushing systems, they act as some of the most efficient earth-moving machines in operation in the world today.

The Bagger 293 is the biggest of these monster machines. Based in Germany, it holds the record for the largest and heaviest land vehicle in the world. It weighs as much as 2,000 adult elephants and is as tall as a 30-storey building. Astonishingly, it can dig a hole the length and width of a football field to a depth of over 25 metres in just one day. The highly efficient machine alone extracts enough coal to power the homes of several million people.

They're mostly commonly used in brown coal (a softer type of coal made of naturally compressed peat) mining as an alternative to blasting. Instead, they scrape away at the soft rock to expose the harder rock that lies beneath before getting to work on extracting the coal. When they're in action the result is literally earth-shaking.

BIG BUCKET DUMPER

The BelAZ 75710 is the world's largest and highest-payload-capacity dump truck

BELAZ 75710
Dimensions
20.6m long
8.165m high
9.87m wide
Weight
360tn

Designed and built by Belarusian automobile engineering company BelAZ to transport rocks in mines and tackle tough terrain in challenging weather, the BelAz 75710 is a far cry from the usual dumptrucks you see on the roads. The vehicle even earned a spot in the *Guinness Book of Records* for its giant size.

Although the basic design sticks with the conventional two-axle setup, the wheels are doubled. The BelAz 75710 boasts eight 59/80R63 tyres as well as four-wheel drive and four-wheel hydraulic steering. These features give the mega machine an incredible turning radius of about 20 metres. The 8.165-metre-high and 9.87-metre-wide 75710 can carry about 450 metric tons in one go, but it isn't just this mega machine's size that gives it monster dumptruck status. It's also powerful, hosting not one but two MTU 65-litre, 16-cylinder, four-stroke diesel engines that drive the vehicle at an impressive maximum speed of 64 kilometres per hour.

A crawler takes a test drive along the crawlerway

BEHEMOTH ROCKET TRANSPORT

How NASA's crawler-transporters move towering rockets from the hangar to the launchpad

CRAWLER
Dimensions
40 x 35m
6.1–7.9m high
(adjustable)
Weight
2,721tn

Crawler-transporter technology

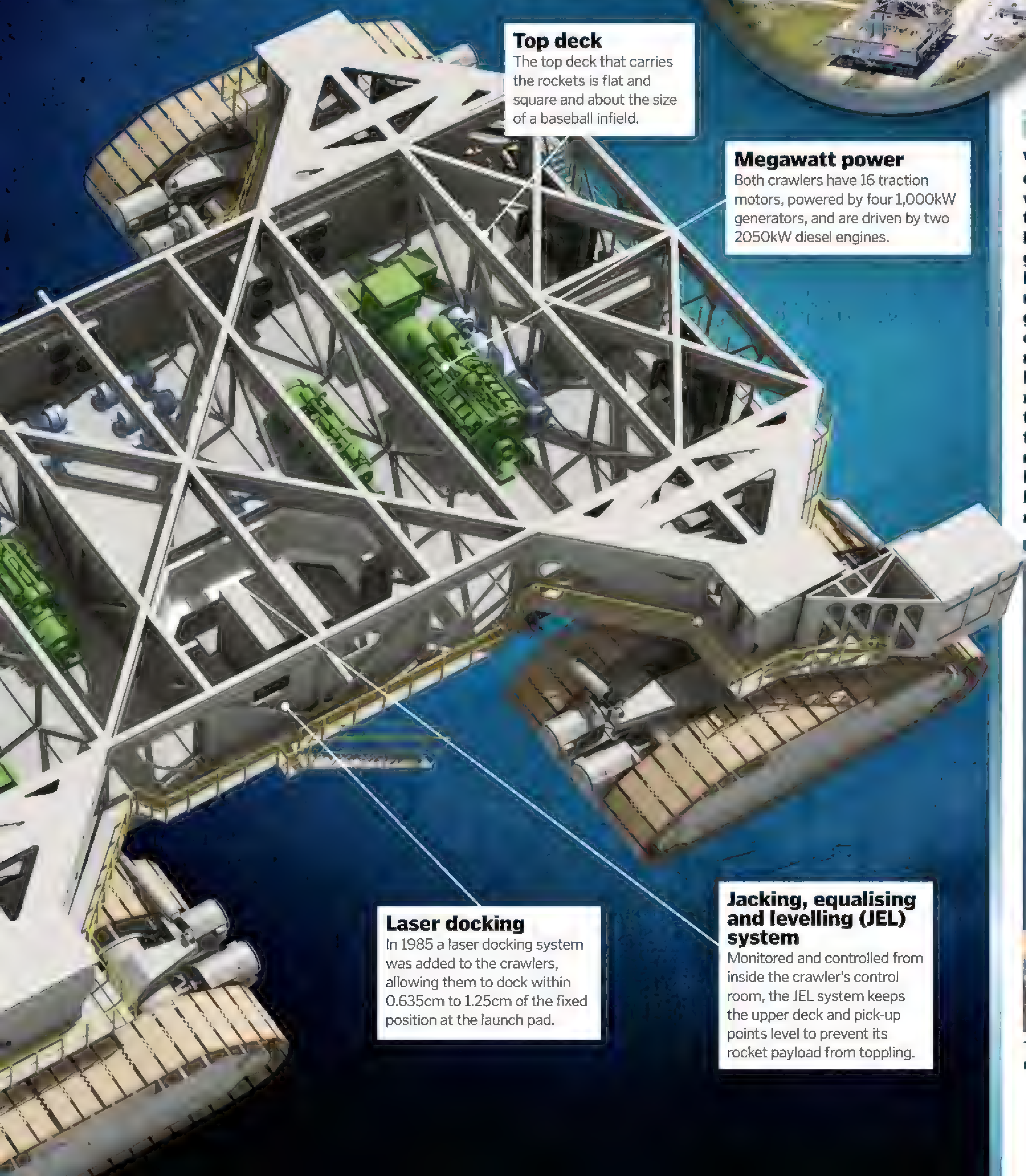
Renovation and redesign has sparked new life into old crawler-transporters

There are many challenges when launching a rocket, many of which happen long before reaching the stratosphere. One of these is moving the rocket from the assembly point to its launch pad. This mammoth task is carried out by twin mega machines – the NASA crawler-transporters. It is their job to move rockets from NASA's Vehicle Assembly Building along the Crawlerway to Launch Complex 39, and they have been used for Apollo and Space Shuttle missions.

The transporters were designed and built in 1965 by the Marion Power Shovel Company using components developed by Rockwell International. 50 years later, rockets are being designed that are much bigger and heavier than the original Saturn V moon rockets the crawlers were crafted to shift. As a result, although they remain the largest self-powered land vehicles in the world, the crawlers are in need of an upgrade. Both machines have already received modifications, including replacing the existing bearings of CT2 with redesigned traction roller assemblies ready to support SLS and Orion. Using these modified crawlers NASA plans to send astronauts further than ever before - first to an asteroid and then on to the surface of Mars.

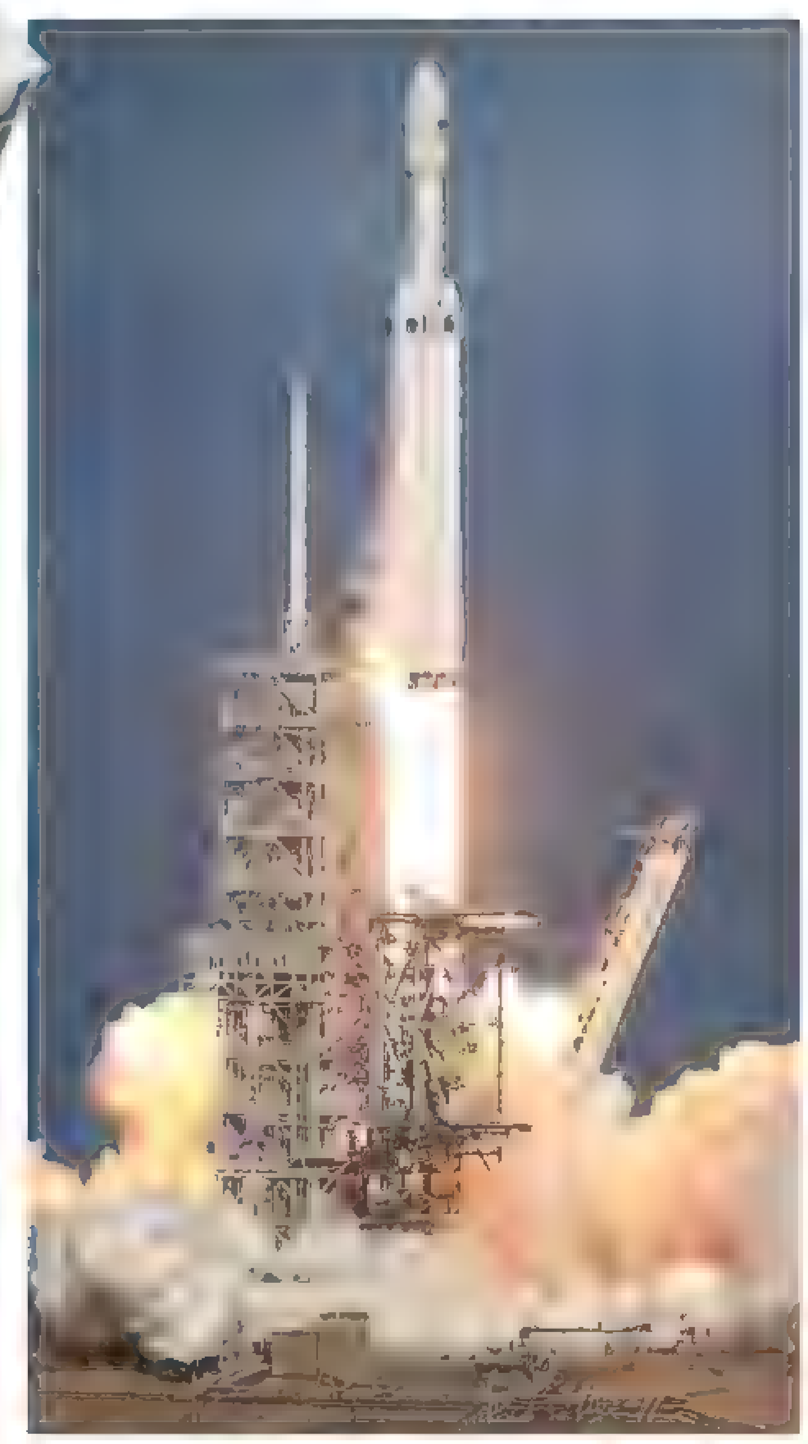
The upgrades have seen the crawlers' lift-load capacity increase from 5.4 million kilograms to 8.2 million kilograms, ensuring the crawler-transporters still have a future supporting NASA missions and will continue to push the boundaries of space exploration for another 20 years.

The full, awesome scale of a crawler in action as it delivers a rocket to its launchpad for take off



Mega machines in space

While the teams working on the crawler-transporters get to work on the upgrades, rockets themselves are getting much bigger. A bigger size means a greater supply of fuel (enabling longer and faster journeys) and more capacity to transport goods into space. SpaceX currently has the biggest and most powerful rocket – the Falcon Heavy. This partially reusable heavy-lift rocket towers at 70 metres and has twice the payload capacity of its nearest competitor. The Falcon Heavy made its maiden flight in February 2018, and there are more planned in the future.



The Falcon Heavy weighs almost as much as three Falcon 9s together

The OOCL Hong Kong has a gross tonnage of 210,890 tons

The Hong Kong's sister ships are called Japan, Indonesia, Germany, United Kingdom and Scandinavia

WORLD'S BIGGEST CONTAINER SHIP

The awe-inspiring OOCL Hong Kong is the first of a new breed of container ship

OOCL HONG KONG
Dimensions 399.9m long
Weight 191,317tn

Passenger ships may have become a thing of luxury and leisure rather than necessity, but cargo vessels remain a vital lifeline transporting more and more goods around the world as our population booms. The largest of these cargo ships has been constructed by South Korean shipbuilder Samsung Heavy Industries, which has started to build six G-class container ships for Hong Kong-based shipping company Orient Overseas Container Line (OOCL). The first of these ships, stacked with brightly coloured containers, will undertake a 77-day round trip to north Europe from Shanghai via the Suez, stopping at ports from Rotterdam to Singapore before returning to Shanghai.

In May 2017 the Hong Kong OOCL was the first to be delivered of the new ships. At almost half a kilometre long, the ship would tower over London's skyline if it was stood upright and would stand taller than the Shard and Canary Wharf. It has been built with a two-stroke, in-line, 11-cylinder MAN Diesel & Turbo (MDT) G-type engine to power the ship at a maximum speed of 21 knots. While this speed is only about four times as fast as a swimming crocodile, it's an impressive feat considering the ship is hauling over 20,000 containers.

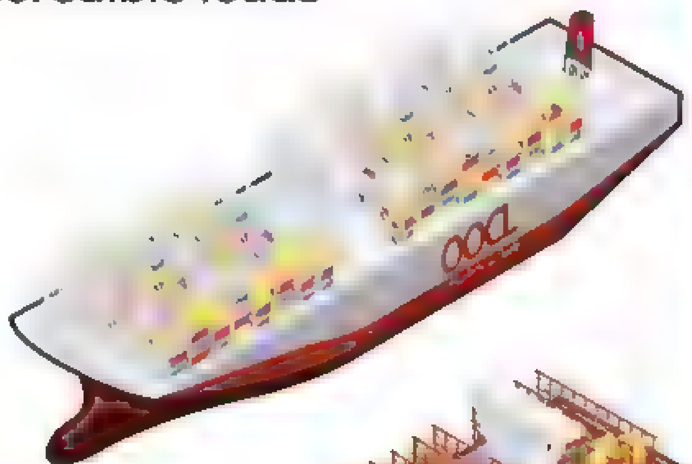
Equipment installed onboard Hong Kong OOCL includes a pair of combined electrically driven mooring winches to keep the ship safely docked and high-tech real-time propeller analytics.

"The ship will undertake a 77-day round trip to northern Europe from Shanghai via the Suez"

Formidable freighters

These ocean-going mammoths can transport incredible loads

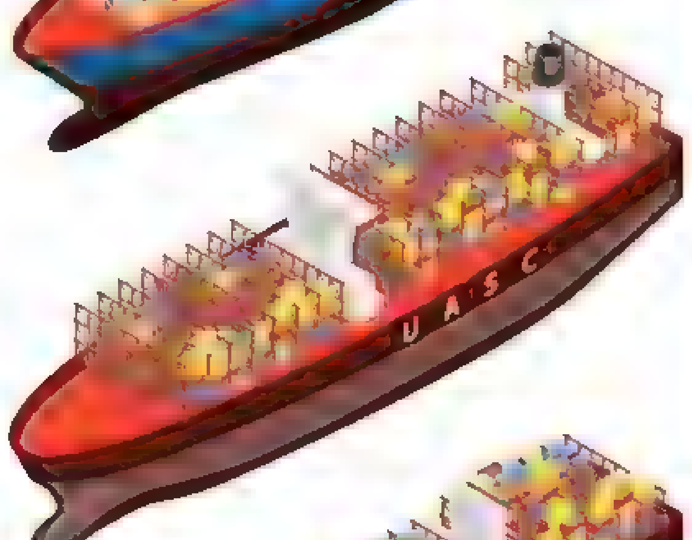
OOCL HONG KONG
Dimensions 399.9m
Weight 191,317tn



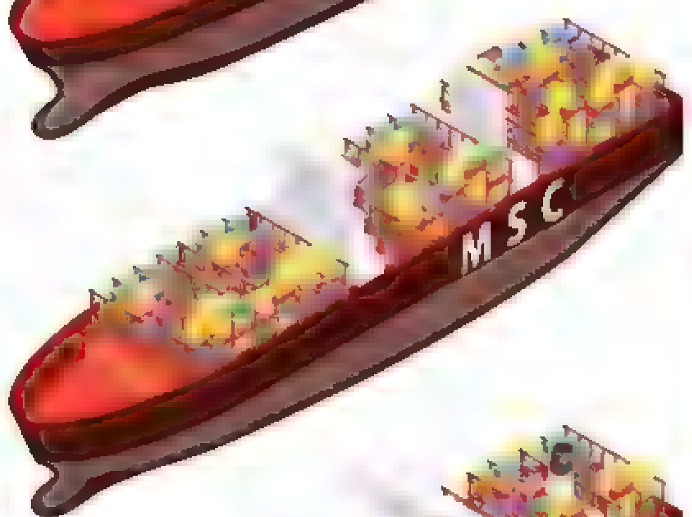
MADRID MAERSK
Dimensions 399m
Weight 210,019tn

MOL TRIUMPH
Dimensions 400m
Weight 192,672tn

BARZAN
Dimensions 400m
Weight 199,744tn



MSC OSCAR
Dimensions 395.4m
Weight 197,362tn



CSCL GLOBE
Dimensions 399.7m
Weight 184,320tn

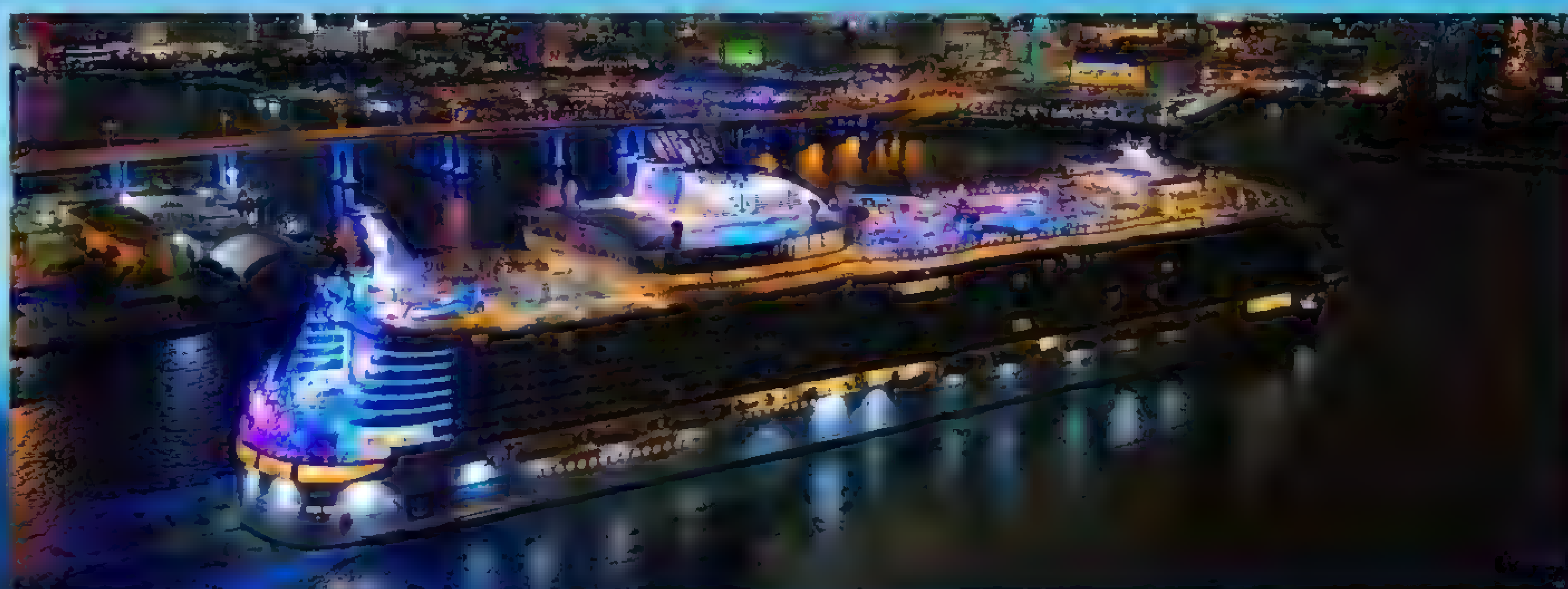
MAERSK 'EEE'
Dimensions 399.2m
Weight 194,153tn

FLOATING CITY

The Symphony of the Seas is the largest cruise liner ever built

The MS Harmony of the Seas is an Oasis-class cruise ship that was delivered to Royal Caribbean International in 2016. Everything from the onboard entertainment to the [illegible] facilities such as a water park, an ice rink and two rock-climbing walls. There is even a slide that children can use to go from their bedrooms to the living area and a bar that serves drinks with a robotic arm.

Constructing this enormous vessel took three years, but now the Symphony crosses the Caribbean with room for an incredible 5,518 passengers in 2,759 stateroom cabins as well as a crew of 2,200.



The Symphony of the Seas cost $1.35 billion to build

SYMPHONY OF THE SEAS

Dimensions
362m long
72.5m high
18 decks
Weight
228,081tn

The Ghan's journey takes 54 hours, including a four-hour stop in Alice Springs

The longest passenger train

The Ghan is one of the world's longest passenger trains. Consisting of 44 carriages and two locomotives, the titanic train is over one kilometre long. Hosting the Ghan is an impressive 2,979-kilometre railway that bisects Australia. Running from Adelaide in the south to Darwin in the north, the route connects both sides of the country for the first time and travels at an average speed of 85 kilometres per hour. It took nearly three years to complete and the Ghan embarked on its first journey in February 2004.

GIANT SKY LAUNCHER

The impressively winged Stratolaunch is designed to take space rockets into the skies

STRATOLAUNCH
Dimensions
117m wingspan
Weight
589.67tn (max launch)

Mega machines have conquered land and the sea, but it will still be some time before we see them in our skies. The first planned mega-plane will be the Stratolaunch. Designed to overcome the challenges of flying through the dense lower atmosphere, the Stratolaunch will launch rockets from runways rather than pads.

Prior to his death in October 2018, billionaire founder of Stratolaunch Paul Allen had ambitious dreams of making launching rockets into space as easy as catching a commercial plane to go on holiday. The idea is that a rocket will be carried by the Stratolaunch to altitude, where the rocket will ignite its own engines, blasting it into space. This would mean that launches could happen on any giant runway, rather than having to carefully time a launch in accordance with the Earth's rotation and the desired position in space.

The Stratolaunch stands as the largest airplane by wingspan ever created. The twin-fuselage catamaran-shaped aircraft have six Pratt & Whitney turbofan jet engines, which are used by Boeing 747s. The right-hand fuselage is the one that features a cockpit, and the other is so far away that from the window it looks like a separate plane parked in the hangar.

Following comprehensive testing the Stratolaunch completed its maiden flight in April 2019, taking off from the Mojave Air and Space Port in California, US, and it will soon be working alongside other companies to aid in launches and deliveries.

Stratolaunch technology

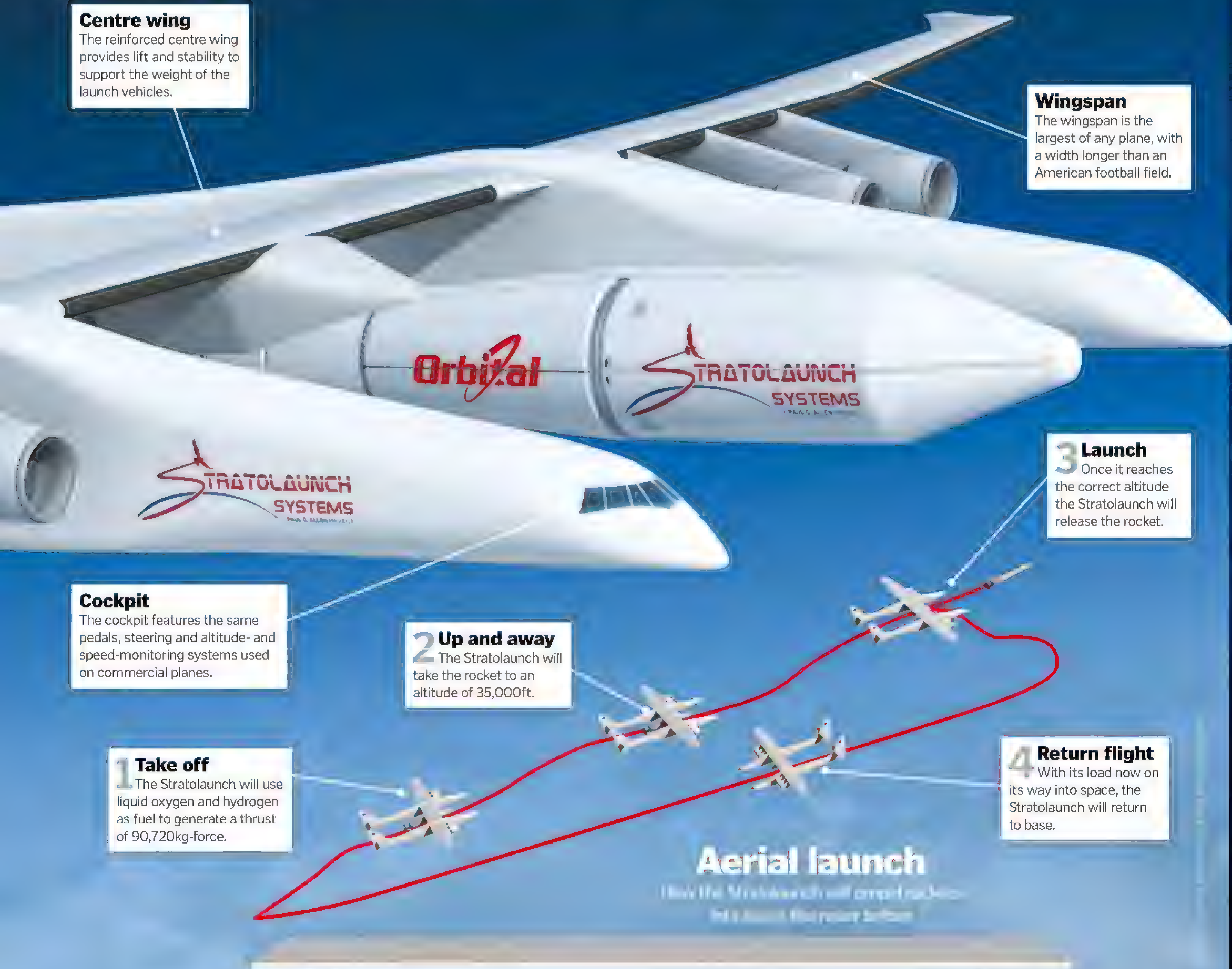
How the Stratolaunch will transport three air launch vehicles, each carrying a 453-kilogram satellite into low Earth orbit

The largest plane you will see in the sky at the moment will be the Airbus A380

Giant flying machines

The biggest commercial plane is the Airbus A380. So far, 232 of these impressive, double-deck, wide-body, four-engine jet airliners have been built. Until the Stratolaunch is completed, the Airbus A380 sets the record of having the largest wingspan – approximately 15 per cent larger than the Boeing 747. The plane can seat up to 853 people, and has a cruising speed of about 1,050 kilometres per hour. The Airbus is the first commercial airliner to have a central wing box made of carbon fibre reinforced plastic and a smoothly contoured wing cross section to reduce aerodynamic drag.


Airbus A380
79.8 metres
Stratolaunch wingspan
117 metres


Centre wing
The reinforced centre wing provides lift and stability to support the weight of the launch vehicles.
Wingspan
The wingspan is the largest of any plane, with a width longer than an American football field.
Orbital
STRATOLAUNCH SYSTEMS
3 Launch
Once it reaches the correct altitude the Stratolaunch will release the rocket.
Cockpit
The cockpit features the same pedals, steering and altitude- and speed-monitoring systems used on commercial planes.
2 Up and away
The Stratolaunch will take the rocket to an altitude of 35,000ft.
1 Take off
The Stratolaunch will use liquid oxygen and hydrogen as fuel to generate a thrust of 90,720kg-force.
4 Return flight
With its load now on its way into space, the Stratolaunch will return to base.
Aerial launch

HISTORY

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Roald Amundsen's research vessel, Gjøa, became stuck in the Arctic ice for almost two years during his Northwest Passage expedition of 1903–1906

RACE TO THE POLES

How pioneering explorers battled extreme conditions to reach the ends of the Earth

Words by **Jackie Snowden**

By the turn of the 20th century, few places on Earth remained uncharted. Since the Age of Discovery, humans had developed the means to cross oceans and explore continents in the interest of developing trade routes and expanding empires. The frozen expanses of the poles presented extreme challenges but offered different incentives: the irresistible lure of the unknown and the glory of getting there first.

PEARY VERSUS COOK

The geographical North Pole lies at the latitude of +90° on a thick shelf of sea ice. The frozen sea shifts with the seasons, making journeys across the Arctic particularly treacherous. Explorers also face temperatures that can drop to -50 degrees Celsius, wind speeds of up to 90 kilometres per hour and the prospect of being hunted by polar bears. After several failed expeditions in the 1800s, in 1909 two successful missions to the North Pole by American explorers were, curiously, reported within a week of each other.

The first was Dr Frederick Cook who, accompanied by native hunters from Greenland, claimed to have reached the pole on 21 April 1908. The team left from Annoatok, Greenland, in February 1908 and travelled an average of 24 kilometres per day using dog sleds, plus a collapsible boat to cross the water where necessary. According to Cook's memoirs he used a sextant to determine his latitude and calculated his position as "a spot which was as near as possible" to the North Pole. However, a perilous return journey over the fractured, drifting ice delayed their return to civilisation and meant they were unable to send word home for another 14 months.

In August 1908, while Cook was missing, presumed dead, his former colleague US Navy Commander Robert Peary set off on what was his ninth Arctic expedition. Using the so-called 'Peary system', his 50-man party rode dog sleds to perform a relay to drop supplies ahead along the route. Unlike Cook, Peary's team did not take boats, so when the ice fractured they were sometimes left stranded for days until the gaps closed up again. When they were moving they covered an average of 21 kilometres per day. Peary took regular sextant measurements to make sure they were still heading north. On 6 April 1909 he recorded a latitude of just over +89° and wrote in his journal, "The Pole at last! [...] my dream and ambition for 23 years. Mine at last."

The announcements of their respective successes almost coincided due to Cook's homeward delays and Peary's remarkably fast return trip. Cook's story was reported on 2 September 1909, while Peary's was published on 7 September, but their achievements were overshadowed by the bitter feud that followed. Almost immediately Peary and his expedition benefactors dismissed Cook's attempt. Peary even took the matter to Congress in order to get the government to officially recognise his achievements instead of Cook's claims.

To this day there are doubts regarding both Cook and Peary's claims; the explorers' accounts and any remaining evidence from both expeditions have been reexamined many times. Questions have been raised about the accuracy of both men's latitude measurements, reported travel speeds and unusual omissions from their journals. It's unlikely that there will ever be a definitive answer as to how close each man truly came to the North Pole, and who – if either of them indeed did – reached it first.

© Alamy

AMUNDSEN VERSUS SCOTT

Less than two years after Cook and Peary's feats first made headlines, preparations for another head-to-head polar race were just getting underway on the other side of the world. In January 1911 two teams of explorers arrived at the Antarctic determined to be the first to reach the South Pole.

The geographical South Pole is located at the latitude of -90° on one of the most inhospitable places on the planet. Antarctica is the coldest place on Earth, holding the record for the lowest observed temperature (at ground level) of -89.2 degrees Celsius. The majority of the inner ice shelf is between two and four kilometres thick, so explorers may experience altitude sickness as they attempt to cross the continent. Antarctica is also home to some of the world's strongest winds; certain areas can experience gusts of over 198 kilometres per hour. What's more, the continent is surrounded by the roughest and stormiest waters on the planet – the Southern Ocean – so both teams faced significant dangers before their expeditions even began.

The competing expeditions were led by Norwegian Captain Roald Amundsen and British Captain Robert Falcon Scott, both of whom were already renowned explorers. Scott had previously tackled the Antarctic during the 1901–1904 Discovery Expedition with fellow explorers Ernest Shackleton and Dr Edward Wilson, making it to -82° latitude – closer to the pole than anyone had reached before. Scott had been granted £20,000 funding from the government for the new expedition, and his preparations were given a lot of media attention.

While Scott's expedition intentions were public, Amundsen kept his own polar plans secret. He was already organising an Arctic expedition when Peary and Cook's claims shattered his lifelong dream of being first to the North Pole. Rather than abandoning the expedition altogether, he revised the plans to make an attempt to the South Pole instead. Even Amundsen's own crew were still under the impression they were heading to the Arctic until he revealed the truth en route.

Scott's team arrived in Antarctica on 4 January 1911 at Cape Evans. While they were setting up base camp and preparing for the trek ahead they were completely unaware that Amundsen's crew had landed just 640 kilometres away in the Bay of Whales on 14 January. Both teams spent most of the year making preparations for the expeditions, laying supply drops along their respective routes before setting off in the Antarctic spring – Amundsen on 20 October and Scott on 1 November.

Key differences between the tactics and equipment of the two crews spelled success for

Robert Peary, 1856-1920

This cartoon illustrates Peary and Cook's feud but also highlights how little was known about the North Pole at the time – penguins don't live in the Arctic!

Polar gear

For any explorer, having the right clothing and equipment can be the difference between life and death

Goggles
Sunlight reflecting off the ice and snow can cause painful temporary vision loss. Goggles with smoked glass were worn by Scott's team to protect against this snow blindness.

Windproof layers
Outdoor fashion brand Burberry provided both Scott and Amundsen's teams with coats and tents made from the company's breathable and waterproof fabric called gabardine.

Native knowledge
Amundsen applied what he had learned from the Inuits in the Arctic to his South Pole expedition. His team wore loose layers and wolfskin fur suits.

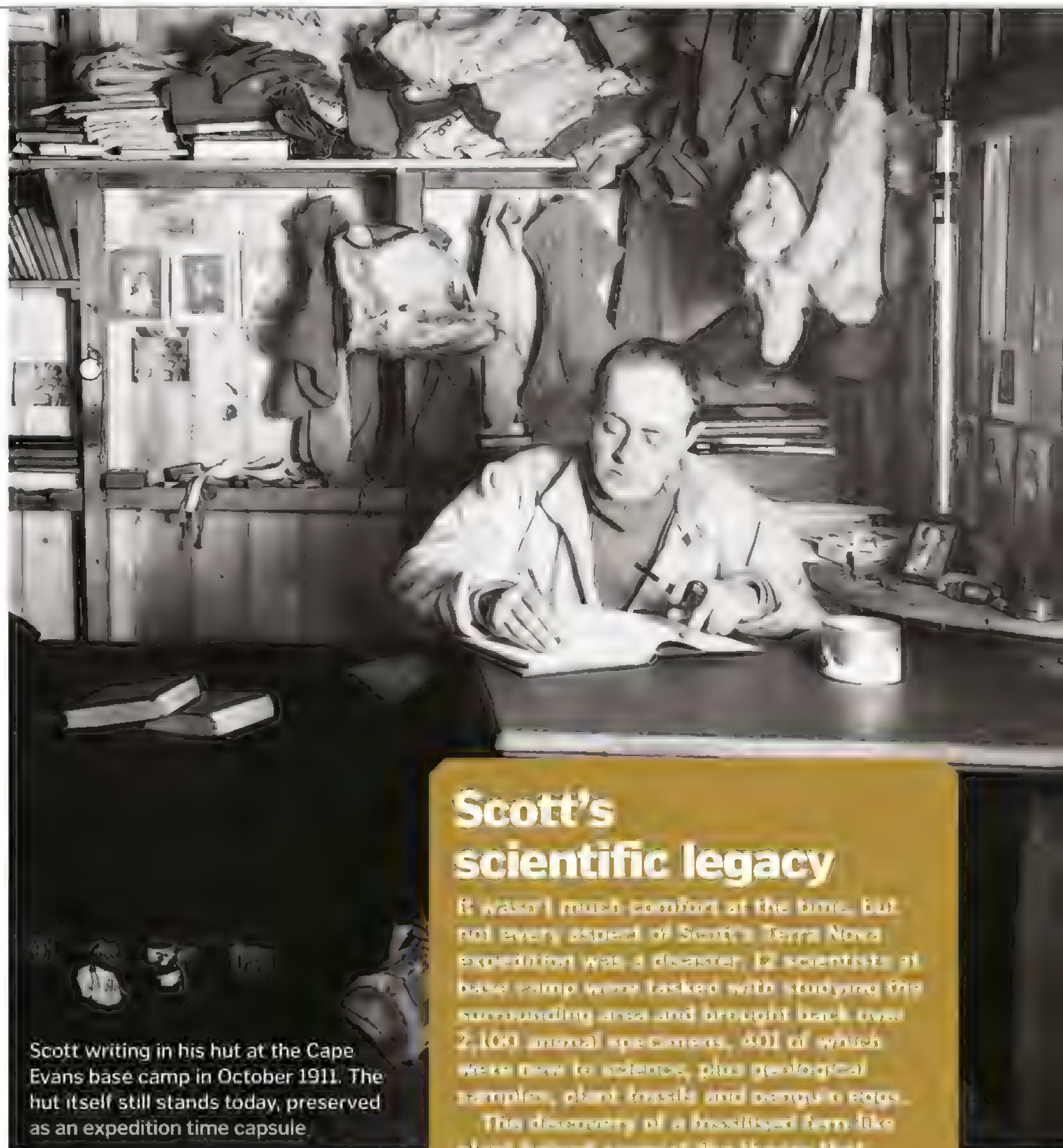
Gloves
In order to be warm enough to protect the extremities, gloves or mittens were often so thick they restricted movement. Explorers had to risk exposing their hands to the elements to perform more intricate tasks.

Scientific equipment
Cameras and navigational equipment were bulky, but these devices were vital to track progress and document the journey.

Boots
Scott's team wore felt-lined, reindeer fur boots that were stuffed with hay to trap more air and provide extra insulation.

Furs
Scott's team wore less fur than Amundsen's. Since they were man-hauling some of their gear they would have overheated in heavy furs.

Amundsen's team (above) reached the South Pole 34 days before Scott's (below)



Scott writing in his hut at the Cape Evans base camp in October 1911. The hut itself still stands today, preserved as an expedition time capsule

one and tragedy for the other. Amundsen's small, specialised team included champion skiers and expert dog handlers. They had specially modified skis, wolfskin furs, windproof suits and knew to wear their layers loosely to avoid sweating so much – a tip Amundsen had learned from the Inuits during a previous Arctic expedition. They reached the South Pole on 14 December and returned safely to base camp on 25 January 1912.

Scott's team was less experienced with both the cold weather and skiing. They brought ponies and motor sleds, but this soon proved to be a grave mistake. Both were unable to cope with the extremes of Antarctica; the sleds failed and were abandoned, and the weakened ponies were eventually shot for food. They reached the pole on 17 January 1912, devastated to find the Norwegian flag already firmly planted there.

Scott's team were suffering from malnutrition, starvation, frostbite and hypothermia as the temperatures dropped to around -30 and -40 degrees Celsius. None of them survived the return to base camp. Scott ran out of rations and fuel and was trapped in his tent by a blizzard, despite being just a few miles away from a supply stash. His tragic last journal entry on 19 March read, "We shall stick it out to the end, but we are getting weaker, of course, and the end cannot be far. It seems a pity, but I do not think I can write more."

Amundsen sent word of his historic success on 7 March 1912 and was duly hailed a hero. However, his glory was later eclipsed when the world learned of the fate of Scott and his men, who were seen as martyrs.

As with Peary and Cook, Amundsen and Scott's journeys have been reexamined over the years – not to dispute whether or not they reached the South Pole, but to determine the combination of factors that led to Scott's failure.

THE END OF AN ERA

These pioneering expeditions of the early 20th century were among the last of what became known as the 'heroic' age of polar exploration. These men were admired for the sheer determination it took to face such harsh conditions with limited resources, pushing their physical and mental strength to the absolute limit in the pursuit of immortality.

This courageous era of discovery drew to a close after World War I, when engineering and technological advancements made such journeys – relatively speaking – much more straightforward to complete.

Scott's scientific legacy

It wasn't much comfort at the time, but not every aspect of Scott's Terra Nova expedition was a disaster. 12 scientists at base camp were tasked with studying the surrounding area and brought back over 2,100 animal specimens, 401 of which were new to science, plus geological samples, plant fossils and penguin eggs.

The discovery of a fossilised fern-like plant helped support the theory that Antarctica was once part of a much larger continent (now known as Gondwanaland). The penguin eggs were collected to try and explore the possible connection between birds and the dinosaurs, which was a relatively new idea at the time.

Since the first polar pioneers people have continued to travel to both the Arctic and Antarctic in the name of science. Today there are a whole host of research stations in the polar regions that are teaching us more about our planet. Antarctica's remote Concordia Research Station is even used to help train astronauts, preparing the next generation of explorers for the uncharted areas that lie beyond Earth.

Robert Falcon Scott, 1868–1912

TRAGEDY AND TRIUMPH

What went right and wrong for Amundsen and Scott?

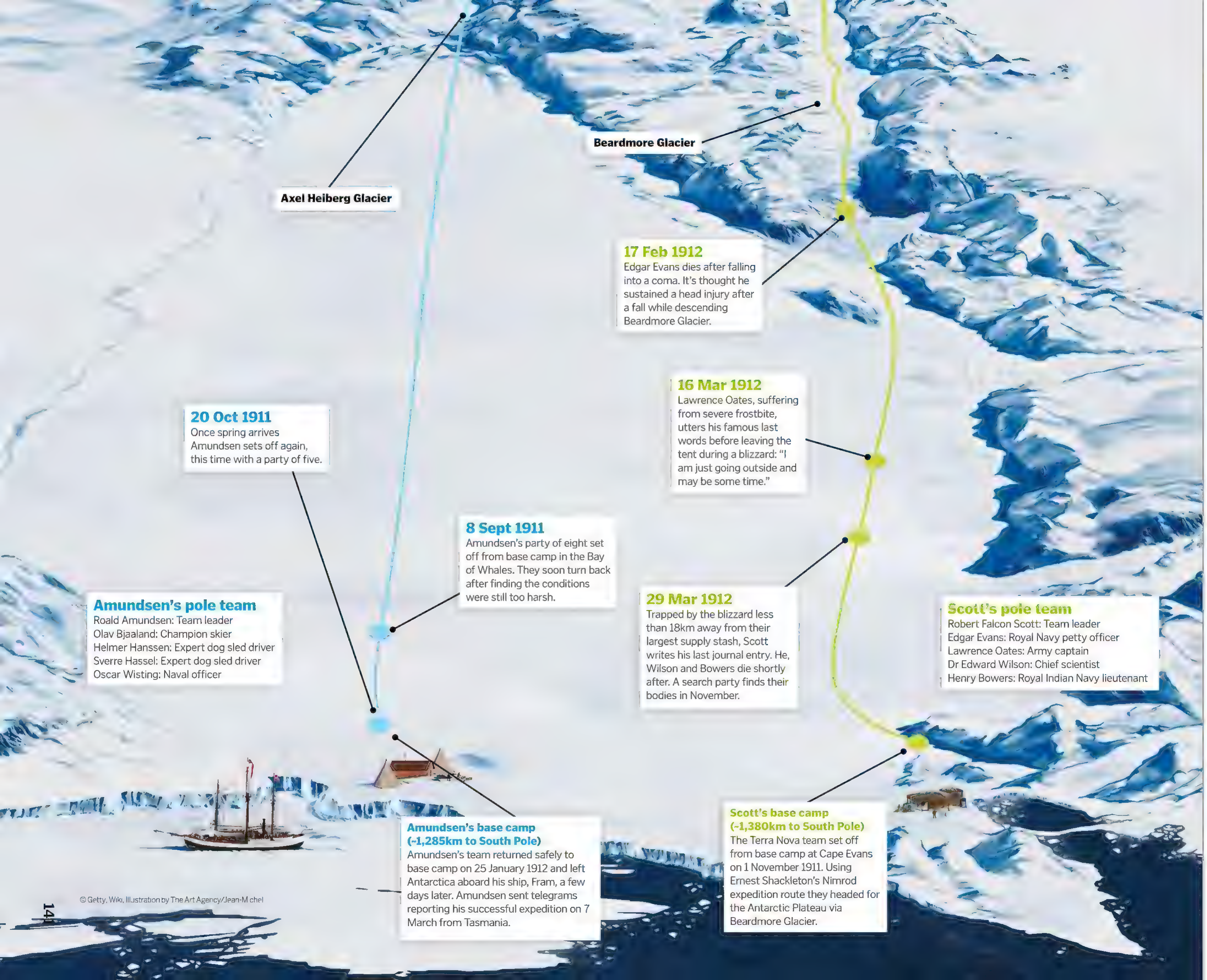
Roald Amundsen, 1872–1928 (disappeared)

14 Dec 1911
Amundsen reaches the South Pole. The team spend several days defining its exact position with sextant measurements.

17 Jan 1912
Scott and his team reach the South Pole, only to discover that Amundsen has beaten them to it.

21 Nov 1911
The team reach the Antarctic Plateau after climbing the newly discovered Axel Heiberg Glacier, which Amundsen named after one of the expedition's financial sponsors.

Photos from Peary (top) and Cook's (above) expeditions from when they believed they'd reached the North Pole


Axel Heiberg Glacier
Beardmore Glacier
17 Feb 1912
Edgar Evans dies after falling into a coma. It's thought he sustained a head injury after a fall while descending Beardmore Glacier.
16 Mar 1912
Lawrence Oates, suffering from severe frostbite, utters his famous last words before leaving the tent during a blizzard: "I am just going outside and may be some time."
20 Oct 1911
Once spring arrives Amundsen sets off again, this time with a party of five.
8 Sept 1911
Amundsen's party of eight set off from base camp in the Bay of Whales. They soon turn back after finding the conditions were still too harsh.
29 Mar 1912
Trapped by the blizzard less than 18km away from their largest supply stash, Scott writes his last journal entry. He, Wilson and Bowers die shortly after. A search party finds their bodies in November.
Amundsen's pole team
Roald Amundsen: Team leader
Olav Bjaaland: Champion skier
Helmer Hanssen: Expert dog sled driver
Sverre Hassel: Expert dog sled driver
Oscar Wisting: Naval officer
Scott's pole team
Robert Falcon Scott: Team leader
Edgar Evans: Royal Navy petty officer
Lawrence Oates: Army captain
Dr Edward Wilson: Chief scientist
Henry Bowers: Royal Indian Navy lieutenant
Amundsen's base camp
(~1,285km to South Pole)
Amundsen's team returned safely to base camp on 25 January 1912 and left Antarctica aboard his ship, Fram, a few days later. Amundsen sent telegrams reporting his successful expedition on 7 March from Tasmania.
Scott's base camp
(~1,380km to South Pole)
The Terra Nova team set off from base camp at Cape Evans on 1 November 1911. Using Ernest Shackleton's Nimrod expedition route they headed for the Antarctic Plateau via Beardmore Glacier.


The remote base is an extensive network of buildings and runways


The U-2 was the first plane known to the public that was developed at Area 51

The truth about Area 51

Myths and conspiracy theories aside, what is really happening at this mysterious air base?

Isolated in the Nevada Desert, a dusty path leads to the heavily guarded Area 51 – an area marked only by orange poles. Covered with blinking surveillance cameras and sensors, the warning signs threaten that deadly force will be used on those who trespass. Has Area 51 been used as a landing spot designated for extraterrestrial passengers on a comet? Perhaps it is the home to aliens held captive by the government or the site of a reconstructed Moon to fake the landing footage? These imaginative stories from conspiracy theorists are very unlikely. Instead, Area 51 seems to be where secret military planes and weapons are tested.

The airfield first began service in WWII as an aerial gun range before the CIA established the site as the location for Project AQUATONE. This project was developing Lockheed U-2, a strategic reconnaissance plane. The new aircraft would allow the military to fly at much higher altitudes and enable them to fly over the USSR without the risk of being shot down. Keeping this secret was a matter of national security, but people noticed the unusually high-flying craft that civilians couldn't explain, so when the test flights started it wasn't long before UFO sightings were reported.

While the U-2 operations stopped in the 1960s the base continued to test experimental planes. The base's primary purpose today is not publicly known, but we can say that almost certainly there are no aliens at Area 51. Almost.

Top security

Whatever is happening in Area 51, the US Government has gone to a lot of trouble to make it difficult for anyone to find out. Historically, the site has been hidden from maps and not recorded on official documents. The land is patrolled by private security guards; they are kitted out with long-range viewing devices, night-vision equipment and 4x4 vehicles with monitors fed by movement sensors around the border of the base. If you are found to be trespassing on the grounds the guards are authorised to shoot to kill. Even if you were to gain top security clearance, you would still be kept in the dark about the true nature of Area 51. Staff arrive on unmarked planes, there are no windows at the facility and teams are not informed about anything outside their own duties.

Trespassing into Area 51 could prove fatal

5 FACTS ABOUT DECLASSIFIED PROJECTS

1 Tacit Blue and Have Blue (1975)
These two planes were the first developed with stealth technology and carried an active radar system to scan ground forces. Have Blue was a prototype for the F-117 Nighthawk stealth fighter and arrived at Area 51 in 1977.

2 The Bird of Prey (1992)
This single-seat, gull-wing experimental aircraft with a radar-evading shape and is rumoured to have also tested active camouflage – the changing of its surface's colour or luminosity to match the surroundings.

3 The Suntan (1960)
This plane was developed as the successor of the U-2 after one was shot down by the USSR. The Suntan used liquid hydrogen fuel and could fly at a much faster 3,200 kilometres per hour.

4 TR-3A Black Manta (1993)
A rumoured project that is described by the website of the Federation of American Scientists as a "subsonic stealthy reconnaissance aircraft", little is known about this aircraft.

5 Aurora (1985)
This code name was accidentally leaked in a budget document and described a reconnaissance and strike plane capable of flying at least 6,100 kilometres per hour and was able to reach anywhere in the world in a matter of hours.

The right to vote

Women have been fighting for equal rights for over a century. Here are some of the landmark moments on the road to suffrage

New Zealand

The first country where all women could vote

New Zealand became the first self-governing country to grant the vote to all women. Years of campaigning resulted in a petition signed by over 30,000 women and the passing of the Electoral Act 1893. However, women would not gain the right to stand for parliament until 1919.

Grand Duchy of Finland

A new government with no gender discrimination

Over 100 years ago, Finland's electoral system was radically reformed, with both men and women given unrestricted rights to vote and stand for election. Prior to this the majority of adults didn't qualify for suffrage.

United Kingdom

British suffrage begins

British suffragettes were fiercely campaigning for women's rights under the motto 'Deeds not Words' prior to WWI. The Representation of the People Bill was passed in 1918, giving women over the age of 30 who held property the right to vote. Their rights were far from equal though, as men could vote from the age of 21, but it marked the start of women's suffrage in the UK.

United States

All states are awarded suffrage

There were many women's rights groups in America, and different states granted suffrage at different times. It wasn't until the 19th amendment to the US Constitution that suffrage was declared every citizen's right.

United Kingdom

Political equality

The Equal Franchise Act awarded women and men aged 21 the right to vote. It was the result of many factors, including changing attitudes, suffrage campaigns and the example set by other countries.

Spain

Playing catch-up

Strangely, Spanish women could stand for parliament but couldn't vote until 1931, and they didn't achieve full suffrage until 1976.

France

Celebrating femme-inism

In 1848, France became one of the first European countries to grant universal male suffrage, but women's rights came much later. They submitted their votes in the first general election since France had been liberated in WWII.

Japan

First election where women could vote

Men were awarded suffrage in 1924 but women were not. In fact they didn't receive equal rights until after WWII.

Pakistan

A milestone in Pakistan

It wasn't until 1956 that women were allowed to vote and seats in government were reserved specifically for females.

Mexico

A Mexican revolution

The decree recognising the full citizenship of Mexican women was published after decades of fighting for equal rights.

Afghanistan

Voting in Afghanistan

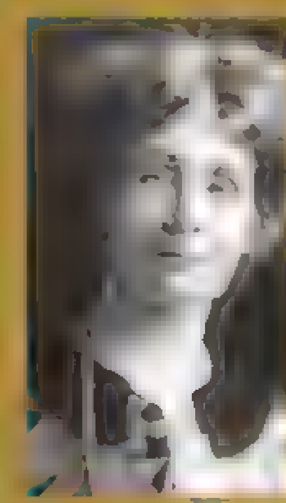
Women gained voting rights after the country won independence in 1919, but this was later overturned and not reinstated until 1964.

Switzerland

Still fighting for suffrage in the '70s

A national vote was required to change Switzerland's constitution, and when the government finally held a referendum for women's suffrage, it was rejected by the majority of men. The question wasn't posed again until 1971.

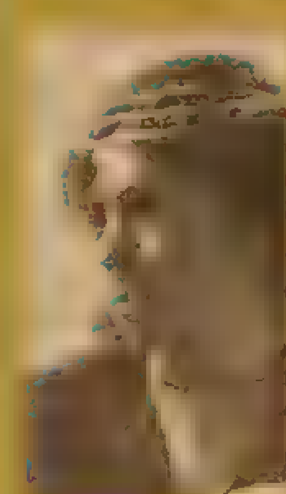
Key figures in the fight for women's rights



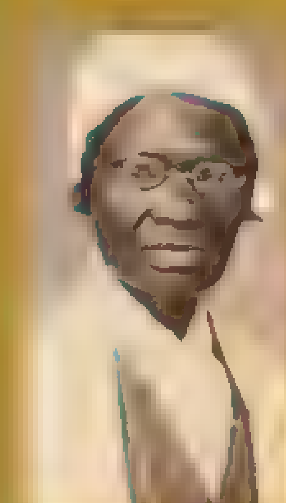
Emmeline Pankhurst (1858–1928)

Kate Sheppard (1847–1934)

Elizabeth Cady Stanton (1815–1902)



Hermila Galindo Acosta (1886–1954)



Sojourner Truth (1797–1883)

Le Mont Saint-Michel

This medieval monastery is a fortified marvel and one of France's most iconic historic sites

The island of Mont Saint-Michel has survived sieges, fires and revolutions over the centuries. While it was once the destination of thousands of travelling pilgrims, today, the it is a tourist hotspot and a World Heritage site.

Located at the mouth of the river Couesnon, the mount was originally entirely cut off from the mainland at high tide. This provided a natural defence against enemies, as even at low tide the exposed sand flats were treacherous to cross. The Bayeux Tapestry even depicts William the Conqueror's knights falling into the surrounding quicksand. During the 19th century a causeway was built, providing a safer link to the mainland at low tide. In 2014, a permanent two-kilometre-long bridge replaced this, enabling tourists to travel across safely.

The island's fortifications were constructed during the 14th and 15th centuries to defend against English armies during the Hundred Years' War. Cannons abandoned by a besieging English general in 1434 are still on display at the gates. Behind the walls, the village of Mont Saint-Michel stretches around the base of the mount, with winding roads leading to the entrance of the abbey.

Many experts have observed how this layout reflects the hierarchy of medieval society, with the church at the peak of the mount, towering above the shops and houses below. However, after the French Revolution the island was claimed by the new government and converted into a prison. Today, Mont Saint-Michel is still a functioning monastery, and a marvel for visitors.

"Even at low tide the exposed sand flats were treacherous to cross"

The abbey of Mont Saint-Michel was built 80 metres above sea level

The Bayeux Tapestry depicts Mont Saint-Michel and William the Conqueror's knights caught in the surrounding quicksand

5 FACTS ABOUT MONT SAINT-MICHEL

1 An English twin
Located in Penzance, Cornwall, St Michael's Mount was its English counterpart – the oldest buildings there date back to the 12th century.

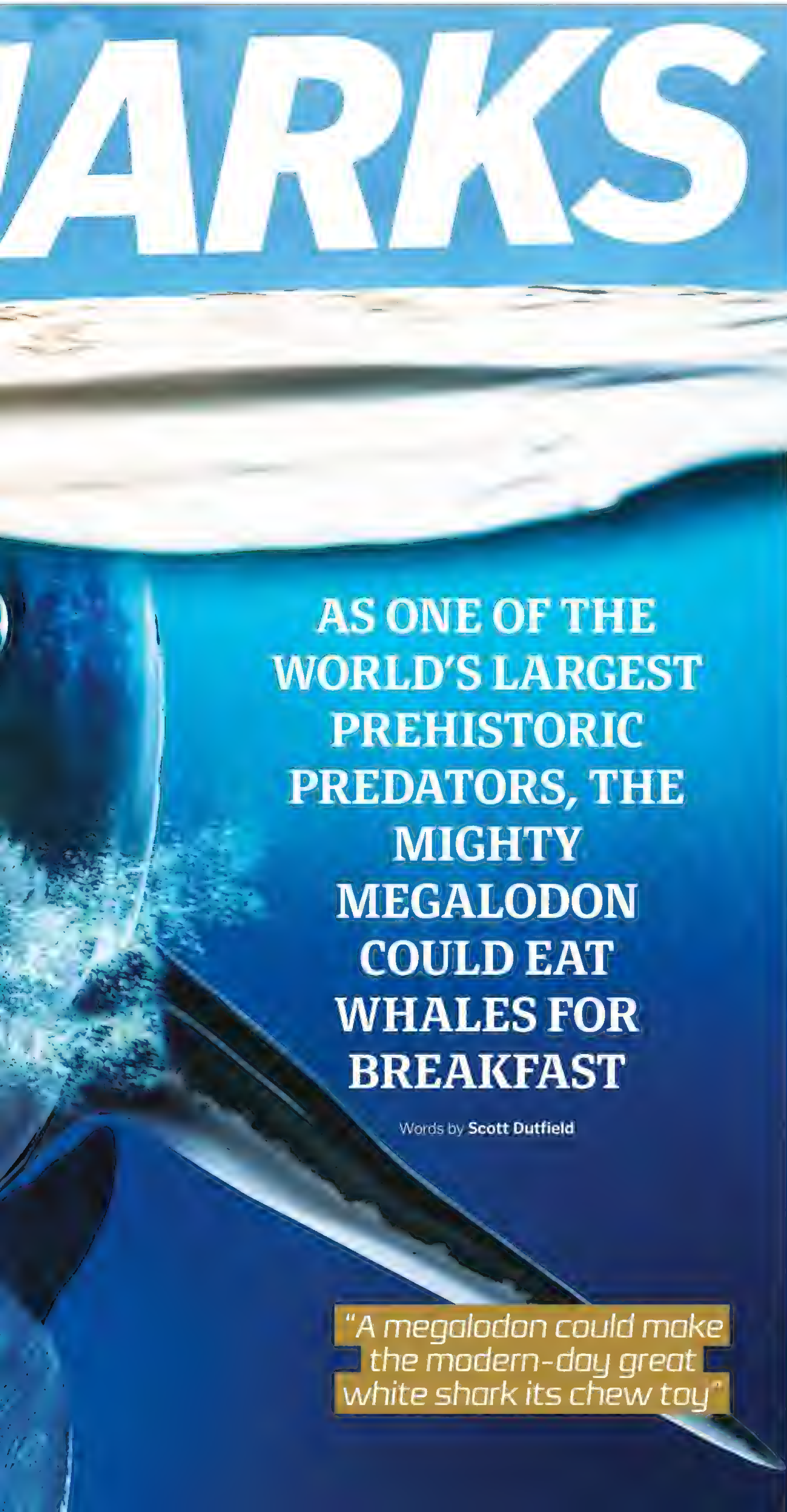
2 Tourist boom
Around 2.5 million people visit the island every year, making tourism the town's primary source of income.

3 Tiny population
In 2015 the island was home to just 33 people, including several monks and nuns who live in the abbey quarters.

4 Medieval mount
The site is over 1,300 years old, with the first chapel constructed in 708 CE and dedicated to the Archangel Michael.

5 Tidal power
Mont Saint-Michel Bay experiences some of the highest tides in continental Europe. There can be a difference of up to 15 metres between low and high tide.

MEGASH



ARKS

AS ONE OF THE WORLD'S LARGEST PREHISTORIC PREDATORS, THE MIGHTY MEGALODON COULD EAT WHALES FOR BREAKFAST

Words by **Scott Dutfield**

> "A megalodon could make the modern-day great white shark its chew toy"

Deep beneath the surface of the Mediterranean, slicing through the open ocean, an iconic silhouette approaches a whale. In a flash it delivers a fatal strike, the whale helpless in the face of nearly 300 serrated teeth as a beast bigger than a bus closes its jaws like a vice. Meeting its end, the whale is but one of the many meals this megalodon will feast upon today. This would have been a regular occurrence around 20 million years ago. Today, whales, along with many other marine mammals, can swim without fear of a giant shark closing in on them with its titanic jaws.

A SHARK'S TALE

The mighty megalodon could make the modern-day great white shark its chew toy. It's estimated that these beasts reached up to 18 metres in length and were armed with around 276 teeth. *Carcharocles megalodon*, as it's formally known, is believed to have navigated the world's oceans during the Neogene period. Megalodon literally translates as 'big tooth', and the species certainly lived up to its name: its teeth could grow up to 18 centimetres and were arranged in five separate rows. This, along with its sheer mass and bite force, made it the most deadly predator known to ever swim the seas.

Its prestigious predatory status has made the megalodon a prehistoric sea monster that is frequently showcased in feature films, where it faces off against other gargantuan beasts. These fearsome fish graced the big screen again in the 2018 feature film *The Meg*, which depicts the

During a megalodon's lifetime it would regularly have shed and re-grown its huge teeth

Today, the great white shark is the largest predatory fish on Earth

megalodon as a giant killing machine hell-bent on hunting down unsuspecting swimmers. In reality, the megalodon would have had bigger fish to fry than comparatively tiny humans. A megalodon would need to consume around a ton of food per day to maintain its 60-plus-ton weight, and on its mega menu were whales, seals and fish – including other sharks. And like other shark species, megalodons didn't just feast on freshly caught prey; they were also scavengers. If the remains of another creature's kill floated by, the megalodon was not one to turn its nose up at a free meal.

The Mediterranean Sea wasn't the only hunting region for these mega sharks; evidence of their predatory presence has been found across the globe's warmer waters. From the coasts of North and South America to the far reaches of the Indian Ocean, during the megalodons' prime it dominated intercontinental waters as an apex predator.

Back in 2010, a team of palaeontologists discovered a 10-million-year-old prehistoric shark nursery in Panama. Over 400 fossilised megalodon teeth were recovered, with most ranging between 1.6 to 7.2 centimetres in length. From these teeth the researchers estimated that the young megalodons would have been between two and 10.5 metres long.

SHARK-TOOTHED COUSINS

It's often said that modern-day great white sharks are smaller 'living fossils' of the once magnificent megalodon. Unfortunately, the palaeontologists trying to understand the truth about the great white's heritage have limited resources available to them.

The fossilised dental records of these mega sharks are scattered across the world, each fragment of tooth an indicator of a shark's size, shape, diet and ancestry. Like modern-day sharks, a megalodon's body was predominately made up of cartilage. Unlike bone, cartilage is rarely preserved in sediment over millennia, so we don't find whole fossilised sharks in the same way we do dinosaurs. However, their centra (the main body of the vertebrae) can sometimes become calcified and preserved, leaving behind what look like rocky hockey pucks. In a similar way as counting the rings of a tree, the layers in these centra can reveal the age of a megalodon at death. The biological biography formed from these tooth and spine samples allows palaeontologists to answer a question long debated in the scientific community: is the modern-day great white shark a direct descendant of the megalodon?

It was previously believed that from mega sharks came the great white, a conclusion based on their dental duality. However, in recent years some palaeontologists have proposed another theory: that great whites descend from an ancient mako shark, and the two evolved side by side. The megalodon itself descended from enormous prehistoric sharks such as the otodus, a near ten-metre-long fish that dominated the oceans 50 million years ago. Both great whites and megalodons do share common ancestry, originating from a group of fish called Lamniformes, or mackerel sharks, as they are also commonly known. As the first shark-like creatures, Lamniformes began their evolutionary journey around 65 million years ago, diversifying and developing along the way into the sharp-toothed species we see today.

THE MEGA EXTINCTION

As invincible as they may appear at the box office, the megalodon could not fight off the forces of mother nature. The demise of these behemoths around 2.6 million years ago is believed to have been the result of several contributing factors.

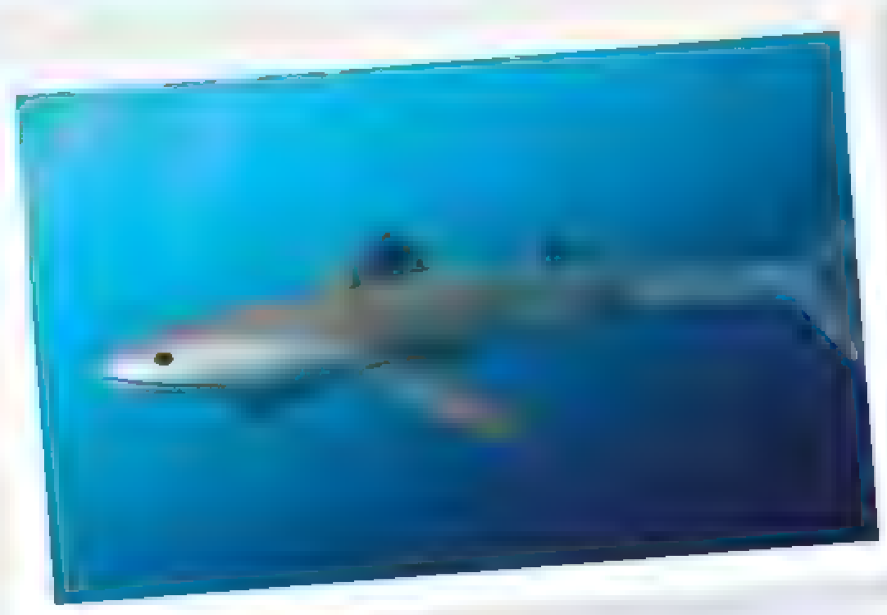
As climatic temperatures became cooler, megalodons moved to warmer waters to hunt and reproduce. However, their prey species – such as primitive baleen whales – were moving

Shark family line

Meet some of the megalodon's prehistoric relatives

390 MYA
Stethacanthus
Sometimes known as the 'ironing board shark', it's still relatively unclear why this fish had such an unusual protrusion, though it has been suggested it was used during mating.

370 MYA
Cladoselache
Unlike the sharks of today, these prehistoric predators had smooth teeth rather than sharp ones, suggesting they swallowed their prey whole.



350 MYA
Falcatus
Found around the shallow waters of what is now North America, these sharks fed on smaller aquatic animals.

270 MYA
Helicoprion & edestus

away from tropical waters, thereby reducing the availability of food. It has also been suggested that megalodons faced competition from the ancient ancestors of the killer whale, which were able to sustain themselves on smaller prey due to their smaller size. As mammals, these whales were also able to store fat and energy in blubber, giving them an extra advantage. As competition for food from growing whale populations increased, megalodons may have simply starved to death.

Although the megalodon may have been wiped from the face of the planet, our fascination with this ferocious fish has not gone extinct. There are those who believe this beast is still lurking in the ocean depths, and some have even claimed to have spotted them. In his 1963 book, *Sharks and Rays of Australian Seas*, Australian naturalist David Stead relayed a tale from a group of fishermen who in 1918 claimed to have seen a gigantic shark that could only be compared to a megalodon. However, this claim, along with the many others that followed, remains unproven.

> "Stories of a living megalodon remain a fishy fairytale"

The story of a living megalodon remains a fishy fairytale. Even so, our oceans are still vastly unexplored, with 95 per cent yet to be studied. Maybe somewhere in the depths of one of the world's oceans there really is a whale about to meet its maker at the jaws of this mega-predator.

Bizarre bites

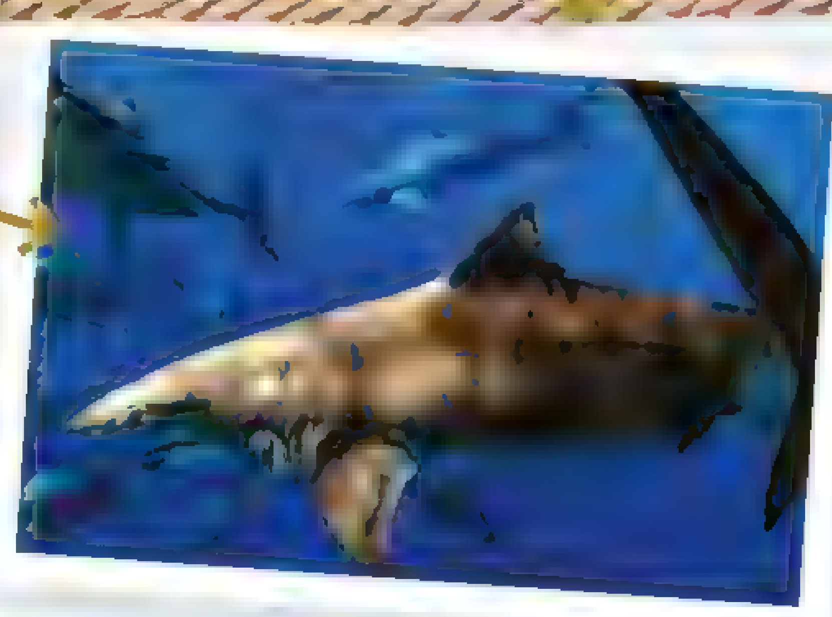
The megalodon was just one of many prehistoric predators whose appearance was more like something from science fiction than reality. The evolution of marine species over time has produced some truly weird and wonderful predators. The helicoprion ('spiral tooth') and edestus ('scissor tooth'), for example, were a pair of fish that really diversified the aesthetics of marine predators with their bizarre arrangements of teeth.

The helicoprion presented its teeth as a central arch in its lower jaw, whereas the mouth of the edestus housed two rows of centralised interlocking teeth. Cruising through the ancient oceans 270 million years ago, this dangerous duo weren't strictly sharks – both instead classified as chimaeras, or ratfish – although they do bear a striking resemblance.

259 MYA
Hybodus
Around 2m long, these prehistoric sharks developed the more solid internal cartilage structure we see in modern-day sharks.

60 MYA
Otodus
The dawn of the giant sharks began with the otodus, a fish estimated to have been around 9m long and one that ate prehistoric whales.

100 MYA
Cretoxyrhina
Also known as 'Cretaceous jaws', these sharks tackled marine dinosaurs as well as other fish for their meals.



23 MYA
Megalodon

SHARKS ON THE BIG SCREEN

Jaws
1975

It might not be a megalodon that swims centre stage in this iconic film, but the infamous great white certainly strikes fear into the hearts of the residents of Amity Island in Steven Spielberg's classic.

The Meg
2018

Thought to be extinct, this film brings the megalodon back to life as it emerges from the deep and kills off a fair few of the main characters. In fact, there's not just one megashark at play here – there are two!

The Shallows
2016

Arguably one of the most intense and suspense-filled shark movies, *The Shallows* superbly depicts the sheer predatory prowess of the great white. An aptly named seagull is another bonus.

Mega Shark vs Crocosaurus
2010

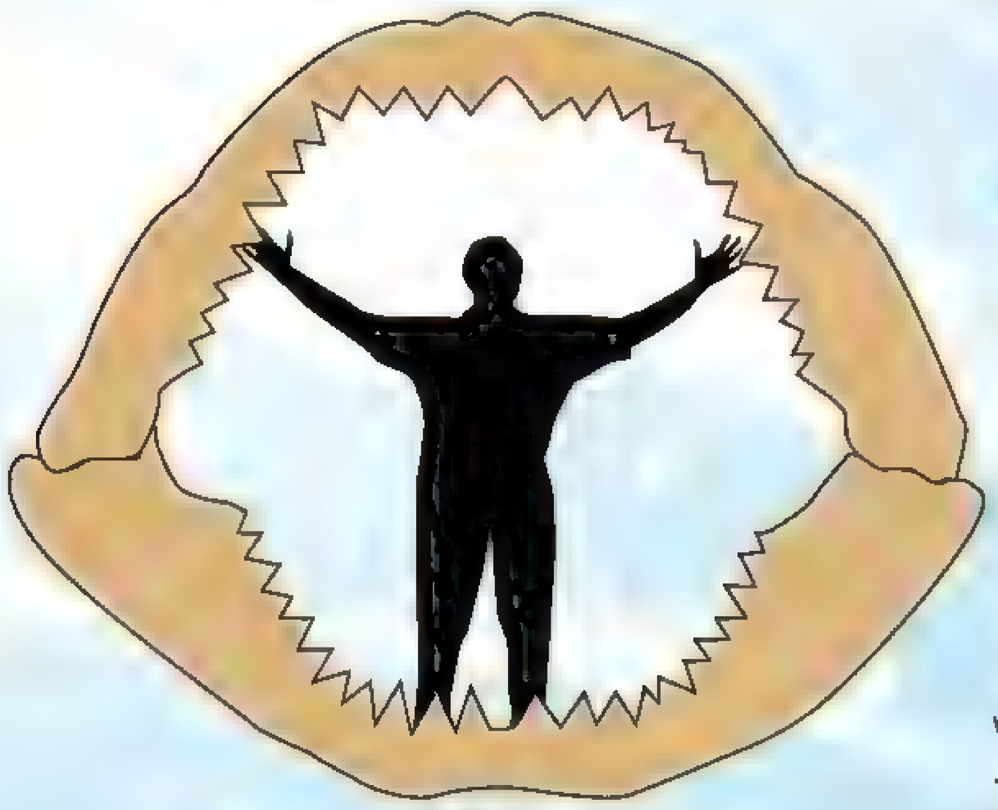
One of the many films that pits a megalodon against another titanic beast (in this instance a 46m-long crocodile), this preposterous instalment reveals the havoc that a battle between the two ridiculously massive monsters would cause.

Sand Sharks
2011

Excellent as a piece of unintentional comedy, this film shows sharks as they have never been seen before, cruising through sand (yes, sand) before devouring an unsuspecting beachgoer in one huge gulp.

THE TOOLS OF A TITAN

Discover what placed the ferocious megalodon at the top of the food chain



Jaws

In order to feast on the flesh of marine giants, the megalodon's open jaws spanned around 3m by 2.5m – easily big enough to have swallowed a human whole.

Speed

With its powerful tail, a megalodon could reach a top speed of 5m/s.

Distribution

With this monster terrorising the seas, nowhere was safe

63.5tn

The estimated weight of an average megalodon

The megalodon hunted several ocean species, including the now extinct dwarf whale, which was similar in size to a minke whale (pictured below)

Scales

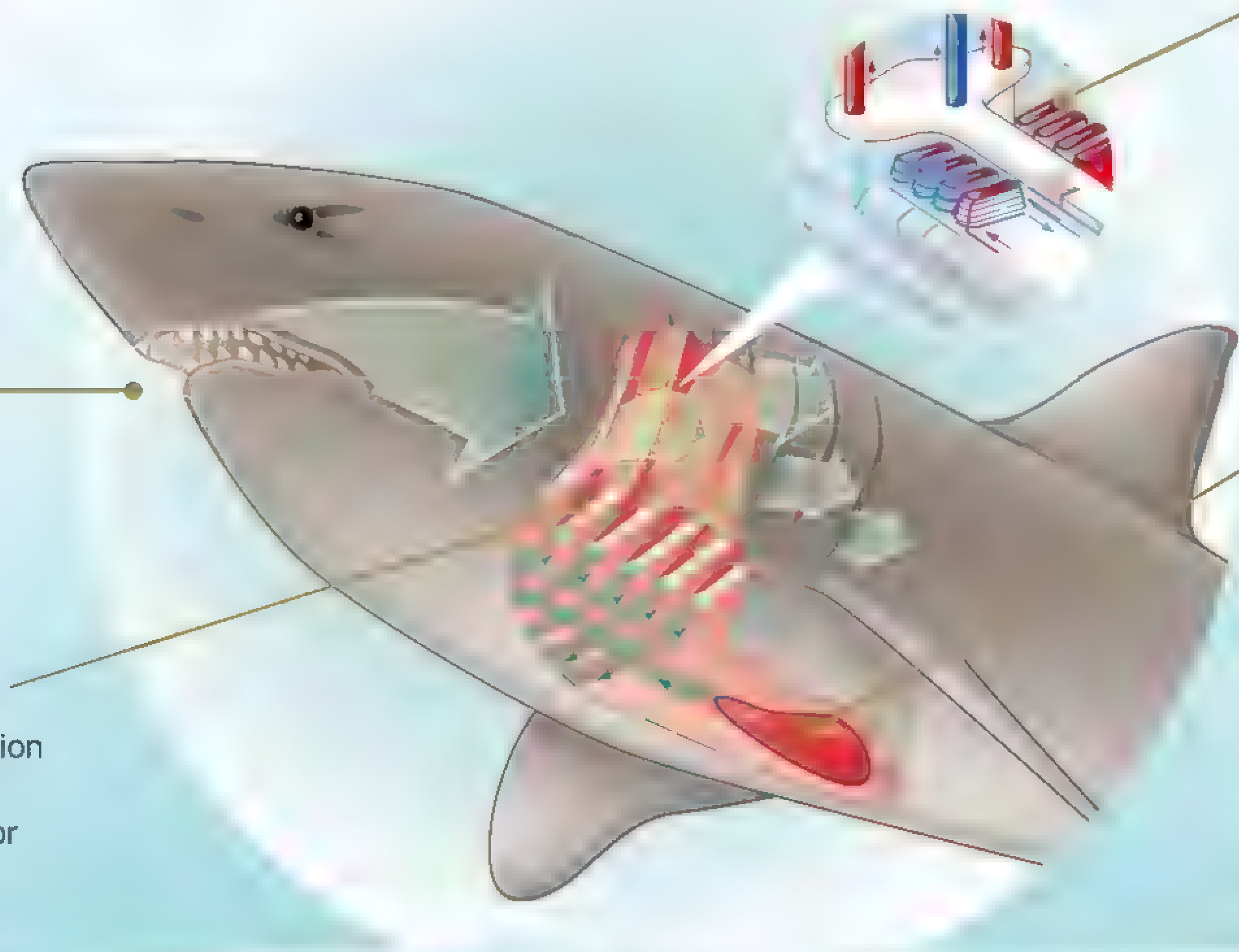
The enormous body of the megalodon is thought to have been covered in dense layers of hard, scale-like armour typical of shark species.

Gills

In the same way sharks today exchange oxygen and carbon dioxide, the megalodon is thought to have had to move constantly to ensure water passed through its gills.

Inside the gills of a giant

It is likely that the megalodon had gills similar to those of modern-day sharks



Water
In order to obtain oxygen for respiration, some species, including the great white, continually swim to force water through their gills, known as ram ventilation.

Gill filaments
These slits are where respiration takes place, but also offer protection against any dirt or debris entering the gills.

Capillaries
This is where gas exchange takes place. Oxygen is absorbed from the passing water into the shark's bloodstream.

Heart
The two-chambered heart directs deoxygenated blood towards the gills, while oxygenated blood is sent around the rest of the body.

"Young megalodons would have been between two and 10.5 metres long"

Teeth
The largest known shark teeth that ever existed, each of the megalodon's 200-plus teeth were serrated to cut through its prey.

The megalodon exerted a bite force of up to

18,600kg

MYSTERIES OF THE MAYA

Deep in the rainforests of Mexico lie the ruins of an ancient civilisation

Mesoamerica was home to some of the most iconic civilisations of the world, each with its own unique achievements. The Aztecs had their elite warriors, the Incas their engineering marvels, and the Maya made apocalyptic predictions. However, the Maya were responsible for much more than the 2012 Doomsday headlines. Accomplished mathematicians, artists, astronomers and architects, they even developed the first writing system in the pre-Columbian Americas.

The Maya ruled much of Mexico and northern Central America, pre-dating the Aztec and Inca empires. Unlike their successors, the Maya did not have a single ruler or centralised authority, their realm instead comprising a collection of city states ruled independently by kings but united in their beliefs and culture. Religion was very important, and they built towering temples to worship their pantheon of gods – there were as many as 250! It was these temples that led 20th-century archaeologists to believe these settlements were "vacant ceremonial centres", inhabited only by priests. They were a peaceful community of forest dwellers – or so those who studied their ways thought.

In reality, war was not uncommon between these Maya cities, often sparked by rivalry over trade and territory, and the victors would leave with more than just status. Prisoners of war were ritually sacrificed, their skulls displayed on wooden trophy racks called tzompantli. The Maya believed human sacrifice would appease and nourish the gods, who had spilled their own blood to create humankind. Even the elite mutilated themselves, usually with stingray spines or blades made from obsidian.

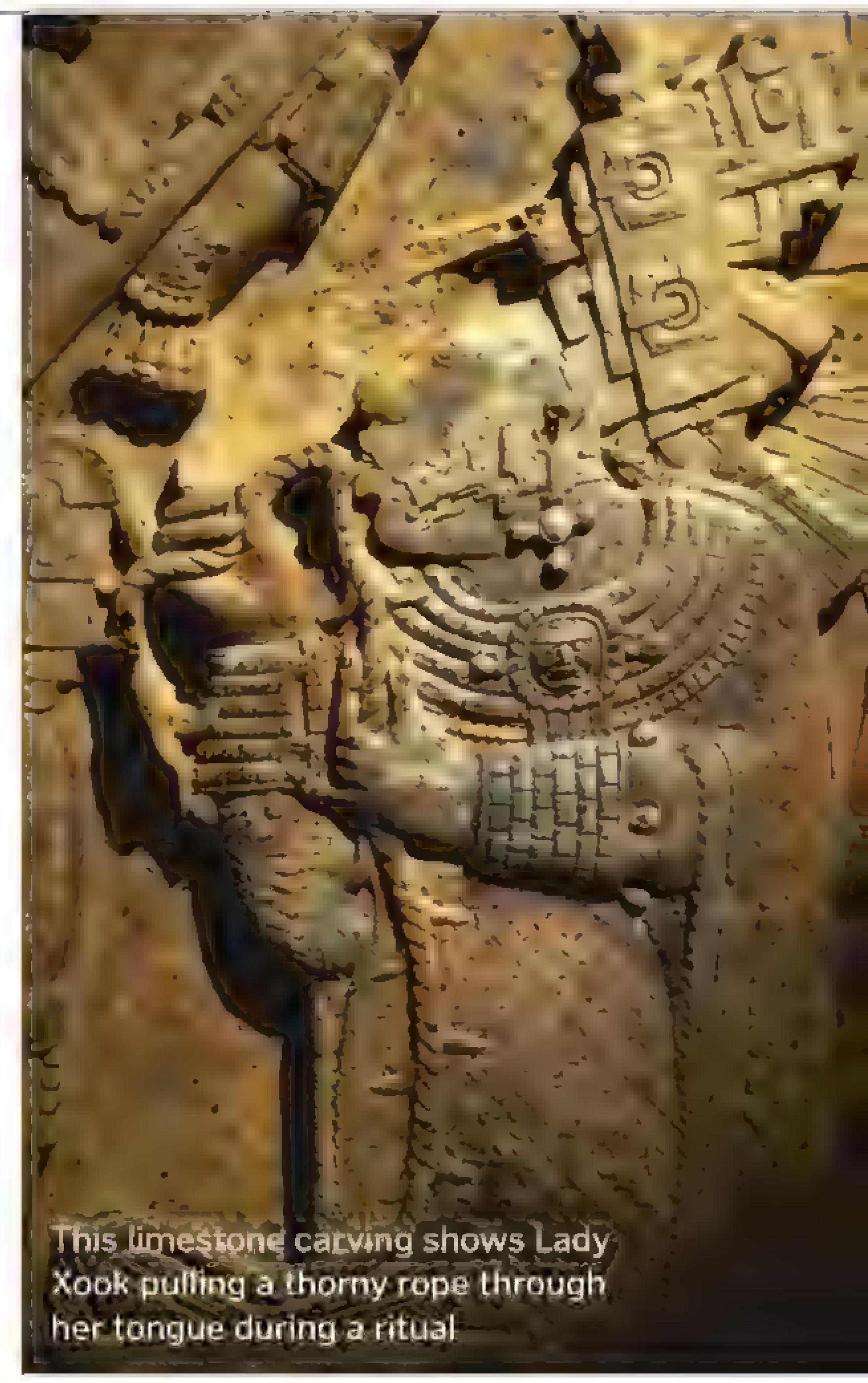
One gruesome carving depicts King Shield Jaguar II holding a flaming torch over his wife, Lady Xook, who is pulling a barbed rope across

"Prisoners of war were ritually sacrificed, their skulls displayed on wooden trophy racks"

The Maya way of life

Your guide to city living, leisure activities and more

A Maya skull resting on the bottom of a cenote once used for ritual offerings in Yucatán, Mexico



This limestone carving shows Lady Xook pulling a thorny rope through her tongue during a ritual

her tongue. These gruesome rituals were thought to be a way of communicating with the supernatural world for guidance. Once blood was spilled onto cloth, it would be burned and the 'vision serpent' would appear in the smoke – a conduit for the gods or spirits of royal ancestors from the Underworld.

The Maya saw the universe as a great Tree of Life. The Middleworld (Earth) was the trunk, the Underworld was the roots and the Upperworld was the branches. Both the Upper- and Underworld were feared and revered – they were where deities and spirits resided – but parts of the Middleworld could tap into these supernatural spheres too. Caves and cenotes (water-filled sinkholes) were considered portals to the Underworld. The word 'cenote' actually originates from the Maya word for 'sacred well', but rather than tossing in a few coins and making a wish, they made offerings in the form of human bodies, ceramics, sculptures and jewels. Their only wish was that this would be enough to keep the gods happy. Incurring their wrath would unleash famine, disease and other horrors upon their population.

On a practical level, these cenotes provided a fresh water supply for farming, which is another reason why many Maya cities were built in close proximity to them. For example, the temple of El Castillo in Chichén Itzá is near to cenotes in the north, east, south and west, and archaeologists believe an entrance to yet another subterranean sinkhole lies underneath the pyramid. This suggests that the Maya chose this site because of its religious significance.

The design and orientation of temples and other buildings were also influenced by the night sky – considered to be the Upperworld. Like much older civilisations, the Maya were keen astronomers. They thought of the sky as a double-headed serpent that swallowed the Sun and the Moon in the west, only for them to reappear in the east. The fact their words for snake and sky were very similar was probably no coincidence. Astronomy was used to plan the Maya ceremonial calendar, in particular the position of Venus. This bright light captured their attention – they saw it as an omen of war and rulers would even organise military campaigns according to the planet's movements.

Observations of the skies also informed farmers when to plant and harvest their crops. The Maya relied on a diet of mostly maize, squash and beans to feed their large population, but the challenging terrain of the rainforest wasn't ideal for agriculture. Instead, they developed an ingenious solution. Canals were built between wetlands to divert the water to where it was needed. They also created raised beds alongside these canals so the crops were safe from the waterlogged soil. Maize was hugely important to the Maya – it didn't just nourish them, it gave them life. According to their creation story, the gods made humans from ground maize and blood.

The majority of the Maya were farmers – men cultivated the crops and women prepared the meals – and they were the lowest in society's pecking order. Next were the merchants and

The wheels of time

The Maya used three calendars simultaneously: the Tzolk'in, the Haab' and the Long Count. The Tzolk'in lasts for 260 days and has a cycle of 20 periods of 13 days. The days are numbered from one to 13, and they each have a name represented by a symbol (glyph). This calendar was used to schedule religious ceremonies.

The Haab' is a 365-day calendar divided into 18 months of 20 days each, and one month of five 'unlucky' days. This measures the time it takes for the Earth to orbit the Sun, but it doesn't account for the extra quarter-day the Earth needs to complete its journey (which is why we have leap years). The Haab' has an outer ring of glyphs that symbolise the 19 months, while dots and bars indicate the days.

Meanwhile, the Long Count tracks what the Maya called the 'universal cycle' of 2,880,000 days (around 7,885 solar years). The Maya believed the universe is destroyed and re-created every cycle. One of the cycles ended during the 2012 winter solstice, which triggered the prediction that the world would end on 21 December 2012.

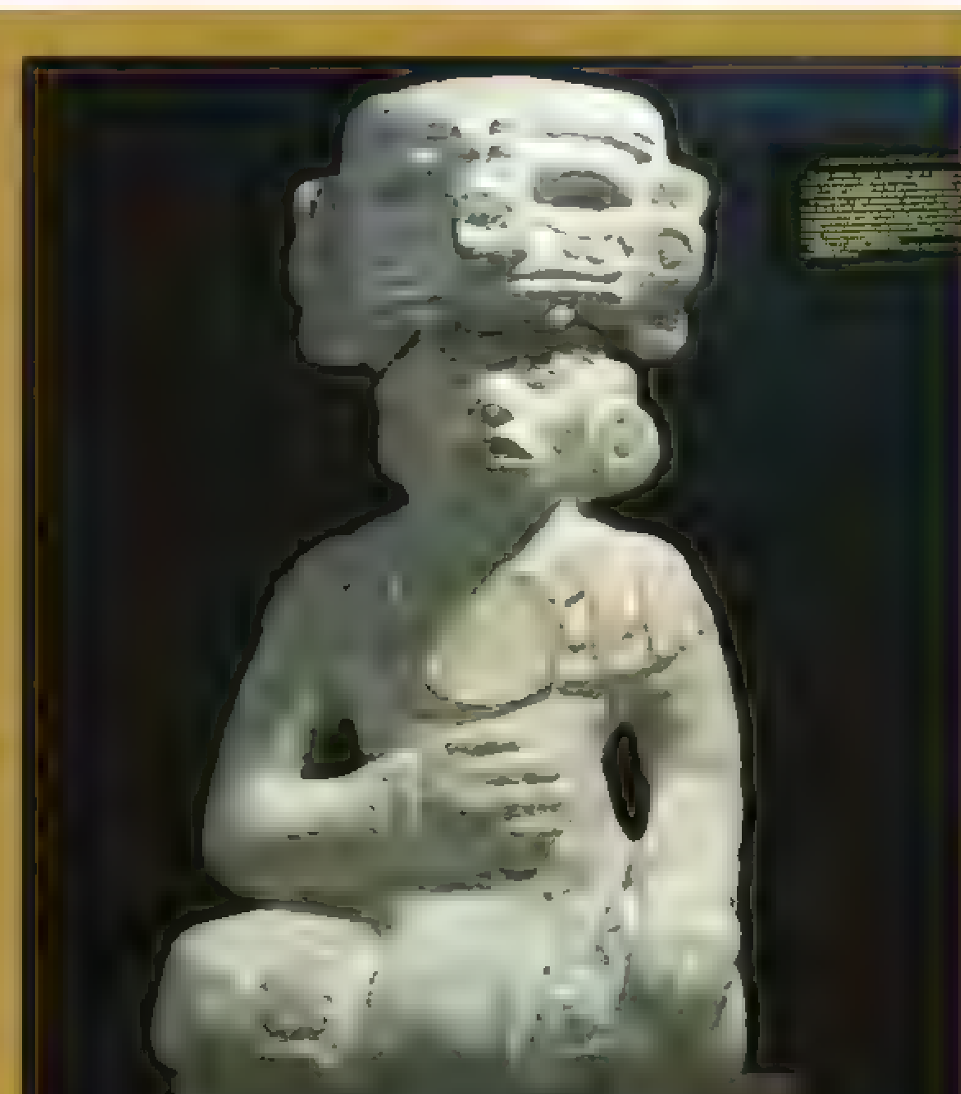
Maya milestones

- **2600 BCE** The Maya begin to settle in the Yucatán area of Mexico.
- **700 BCE** Writing develops in Mesoamerica using symbols called glyphs.
- **300 BCE** Maya society adopts a hierarchy dominated by nobles and kings.
- **250 CE** The Classic Period begins, when the Maya reached the peak of their powers.
- **900 CE** The collapse of the southern lowland cities signifies the end of the Classic Period.
- **1200** Northern cities begin to be abandoned, including Chichén Itzá.
- **1511** Spanish conquistadors arrive in Yucatán, bringing diseases that would kill much of the native population.
- **Mid-1500s** Spanish cities were established in the Maya region. The last Maya city remained independent until 1697.

The end of the Maya

By the time of the Spanish conquest in the early 1500s, many Maya cities were already in ruin. They had been abandoned hundreds of years before, leaving experts clueless as to why. One theory is that warfare tore them apart, and a recent gruesome discovery supports this. The skeletons of 31 assassinated royals and nobles were unearthed in the ruins of the Maya city Cancuén. The area was abandoned soon after, as were other nearby cities.

Others believe collapsing trade routes, diseases or severe droughts were to blame, and recent evidence suggests the latter certainly dealt a crippling blow. Scientists have found that rainfall plummeted by half during the period of the Maya's demise, sometimes by as much as 70 per cent. This drought would have turned land to desert, evaporating water from lakes and dooming crops to dust. Perhaps as a sign of their desperation, masks of the Maya rain god Chaac can be found among the ruins. The Classic era of the Maya had come to an end, but some major cities like Chichén Itzá continued to thrive until the Spanish arrived on their shores.



A statue depicting a priest to the rain god Chaac, found in Chichén Itzá

artisans, who traded goods with other city states and produced art to give thanks to the gods. Then came priests – the keepers of knowledge. They recorded key events using their own writing system of hieroglyphics, used mathematics to calculate the time and movement of the planets, and performed ceremonial rituals. The only people more important than priests were the nobles and the king, who had complete power over their city. They occupied enormous palaces – one was the size of several football pitches – and were thought to become gods after death.

Clearly the Maya way of life heavily revolved around the supernatural, but that didn't stop them from being a little superficial too. In Maya society an elongated head shape was all the rage, so parents would flatten their babies' soft skulls with wooden boards to create the desired effect. It's thought that this beauty trend may have been inspired by a beloved maize god whose head vaguely resembled a husk of corn. Kernels may have also inspired the fashion for filing teeth into points. The wealthy would have holes carved into their enamel to hold precious stones, such as jade. This material was valuable to the Maya because it was associated with water and the colour of the maize plant. Ear, lip and nose piercings were also popular, while some brave Maya opted to have tattoos, which were carved into the skin. Plenty of jade jewellery and bright body paint completed the look.

The Maya thrived from 250 to 900 CE, what historians call the Classic Period. But then something happened that triggered entire cities to be abandoned. What exactly caused this is still debated – deforestation, drought, wars – and speculation is rife. Some communities survived, but by the 11th century the Maya were past the peak of their powers. When Spanish conquistadors arrived in the mid-1500s they were eventually overpowered. Bows, arrows and swords made of obsidian were no match for modern technology. The Spanish were armed with iron, steel, gunpowder and carried with them foreign diseases. The latter proved fatal for the majority of the remaining Maya population. Their cities were left in ruins and their written records were destroyed – only four books (codices) remain today. Yet despite the odds, archaeologists are constantly making new discoveries, and we know substantially more than we did even a few decades ago. There could be more secrets yet to be revealed.

A depiction of a Maya maize god, with elongated head and a headdress resembling maize fibres

A jade funerary mask of the legendary ruler King Pakal

"In Maya society an elongated head shape was all the rage"

LIGHTS CAMERA ACTION

Go behind the scenes of Hollywood's Golden Age and the making of a multi-billion-dollar industry

Words by **Jodie Tyley**

The year is 1929 and Hollywood's Roosevelt Hotel has opened its doors to the first Academy Awards. There's no red carpet and no viewers watching at home (it wouldn't be aired on television until 1953). The ceremony lasts 15 minutes and the 270 guests already know who's won because the results were announced months earlier. A far cry from today's media circus, the inaugural awards was a private dinner for filmmakers and stars held to celebrate an industry in the midst of its Golden Age.

From the 1920s to the 1960s, one Los Angeles neighbourhood became the movie capital of the world. It was a period of huge growth, both in terms of movie milestones and the emergence of major motion picture studios. But why Hollywood? Well for one thing the long daylight hours of southern California and the variety of landscapes, from desert to forests, made it an ideal shooting location. Land was also cheap – perfect for setting up studio backlots – and taxes were low. It was a no-brainer, and by 1915, 60 per cent of US film production was based there. Even world wars and the worst economic event in history couldn't prevent the meteoric rise of this star-studded industry – one that

actually owes more to science and technology than glitz and glamour.

By the time of that very first Academy Awards ceremony the movie world was moving at a blistering pace and the era of silent film was coming to an end. Of course, the term 'silent movie' is a misnomer, because these films were never viewed in complete silence. Theatres employed musicians to play live, ranging from solo pianists to full-blown orchestras, and the film distributors would often provide cue sheets to help their performance.

Despite new technology making it possible to synchronise audio with visuals, Hollywood was hesitant. Making the costly conversion to sound would damage overseas appeal by creating language barriers, and what would happen to the studios' archive of silent movies? It was a risk, but one that film producer Sam Warner convinced his siblings to take. Warner Brothers was a small studio with big ambitions, and Sam believed that synchronised soundtracks could boost their business.

Don Juan (1926) was the first film to feature a score and sound effects using the sound-on-disc system Vitaphone. The record was played on a turntable, which was connected to the film projector by a motor that controlled the speed. The film was a critical and commercial success, and the following year the studio released the first movie with dialogue when Al Jolson ad-libbed in between musical numbers in *The Jazz Singer*. The silence of cinema was broken when he called to the orchestra, "Wait a minute, wait a minute. You ain't heard nothin' yet!"

The Wizard of Oz was released in glorious Technicolor

These so-called 'talkies' were a sensation, but those in front of the camera were less enamoured with the new medium. Actor Mary Pickford famously said that adding sound to pictures was "like putting lipstick on the Venus de Milo". She wasn't the only one who thought movie stars should be 'screened not heard' either, as the talkies spelled disaster for many careers. Vilma Banky's image as the all-American sweetheart was shattered when audiences discovered she spoke with a Hungarian accent. Charlie Chaplin, on the other hand, chose to stay tight-lipped and didn't appear in a speaking role until 1940. The plot to *Singin' in the Rain* (1952) poked fun at this difficult transition, as Gene Kelly's character and his co-star are forced to adapt to the new era.

Talkies presented technical challenges too. Early microphones had such limited range that actors had to speak directly into them, restricting performances. The mics were also omnidirectional and picked up unwanted sound from the recording equipment. Cameras were confined to glass booths, which only allowed the lens to be tilted 30 degrees on a tripod. This, combined with the actors' inability to walk and talk, made these early sound films very static. The solution: soundproof camera casings called 'blimps', which enabled operators to follow the action, mounting the cameras on wheeled carts called 'dollies'. Microphones were then hung from boom arms above the actors.

The success of sound saved American cinema, even when the 1929 Wall Street Crash

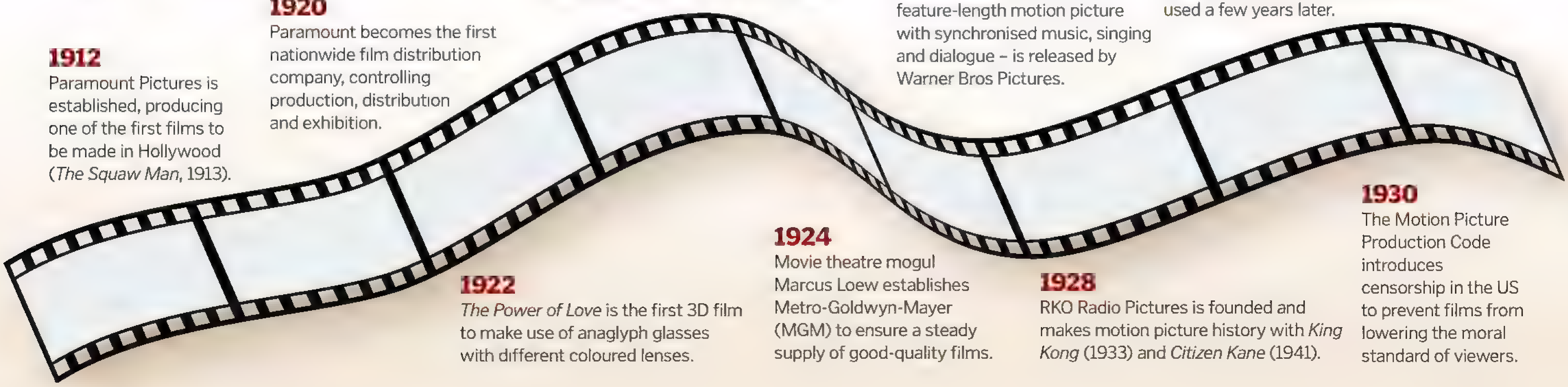
A sign of the times

Those iconic letters on the hillside are synonymous with movies and stardom, but it was originally an advert for a housing development. *Los Angeles Times* publisher Harry Chandler was branching out into real estate and splashed out on the $21,000 'Hollywoodland' sign in 1923. The original 13 wood and iron letters were over 13 metres tall and around nine metres wide, rigged together by scaffolding and telephone poles. No one could miss it – especially with the thousands of light bulbs flashing around the letters like a mob of paparazzi.

However, by the mid-1940s the sign was on the blink. Some repairs and the removal of the last four letters bought it some time, but by the 1970s it needed completely rebuilding. This time it was celebrities that saved it. *Playboy* founder Hugh Hefner hosted a lavish fundraiser where letters were 'auctioned' and the sign was saved. Then in 2010 Hefner pulled a rabbit out of his hat again by making a last-minute donation to rescue it from property development.

[illegible]

Movie milestones



1912
Paramount Pictures is established, producing one of the first films to be made in Hollywood (*The Squaw Man*, 1913).

1920
Paramount becomes the first nationwide film distribution company, controlling production, distribution and exhibition.

1922
The Power of Love is the first 3D film to make use of anaglyph glasses with different coloured lenses.

1923
Warner Brothers Studios is founded by siblings Albert, Sam, Harry and Jack.

1924
Movie theatre mogul Marcus Loew establishes Metro-Goldwyn-Mayer (MGM) to ensure a steady supply of good-quality films.

1927
The Jazz Singer – the first feature-length motion picture with synchronised music, singing and dialogue – is released by Warner Bros Pictures.

1928
RKO Radio Pictures is founded and makes motion picture history with *King Kong* (1933) and *Citizen Kane* (1941).

1929
The first Academy Awards ceremony is held in Hollywood. The name Oscar is used a few years later.

1930
The Motion Picture Production Code introduces censorship in the US to prevent films from lowering the moral standard of viewers.

Left: *Singin' in the Rain* (1952) is about the transition from silent films to 'talkies'

bankrupted millions and led to mass unemployment. Theatres saw weekly attendances rise from 60 million in 1927 to 90 million in 1930, financing the mergers and takeovers that followed. The 'Big Five' major film studios emerged: Paramount Pictures, Metro-Goldwyn-Mayer, 20th Century Fox, Warner Brothers Pictures and RKO. It was the birth of the studio system, where companies controlled every aspect of the industry – they produced the films, distributed them and screened them in their cinemas. Actors were even employed on long-term contracts, rather than for specific jobs.

Hot on the heels of sound films came the technology to transform black-and-white visuals into colour. For decades, filmmakers had hand-painted their footage frame by frame – an expensive and painstaking process – while others used dyes to tint their film. The first successful colour process was Kinemacolor in the early 20th century. It used alternating red and green filters, creating a clever optical illusion where the two colours appeared to be combined. However, this method was far from perfect and the lack of blue was very apparent. The introduction of Technicolor's three-colour camera in 1932 changed all that.

It used the principles of colour photography invented by physicist James Maxwell in 1861 when he produced the first colour photo using red, green and blue filters. Technicolor's camera captured these three colours by using three separate strips of film and combining them to create a full-colour image. One of the most famous showcases of this new technology was *The Wizard of Oz* (1939), which used Technicolor as part of the storytelling when Dorothy leaves her sepia-toned reality for the dazzling land of Oz. Her iconic ruby slippers were silver in the book, but they were not seen as dramatic enough in this new age of cinema.

When studios commissioned Technicolor, they didn't just receive the three-strip camera; the package included a crew of camera operators and a colour consultant, as well as the film stock processed in their labs afterwards.

However, the company's rise had not gone unnoticed, and in 1947 the US Government charged Technicolor with monopolising the production of colour movies. It was part of a campaign that also saw the Department of Justice file a lawsuit against all the major studios for their control over the film industry. Hollywood's studio system was dead.

Companies such as Paramount were forced to sell their theatres, while RKO sold their film rights to TV stations in order to recoup their losses. It was a huge win for the TV industry, which was steadily luring viewers away from the big screen. By the mid-1950s TV networks had the rights to a catalogue of movies and were also producing their own shows.

Hollywood competed by making even bigger exhibition screens. A new projection system called Cinerama used three synchronised cameras to capture an image three times as wide as a regular film. The Cinerama film was then screened using three projection booths onto a curved screen to create an immersive experience. Studios also experimented with 3D, and the content of their movies became more adult at a time when TV had strict moral regulations. Despite these efforts, the 1960s signalled the end of Hollywood's Golden Age.

Sound effects

Creaking doors, smashing glass, rustling paper – everyday sound effects such as these are reproduced for film and added in post-production. They're known as Foley effects, named after the man who developed the craft. Jack Foley was the sound director at Universal Studios from 1927 to 1960, recording audio of footsteps and other background noises that the microphones couldn't pick up.

Footage would be projected onto the screen and he would create the sound effects in time with the action. To recreate the sound of three men going for a stroll he walked with a cane, and for an entire Roman army marching, he jangled keys (*Spartacus*, 1960). Today, those that follow in his footsteps are called Foley artists, and unlike Jack, they are recognised for their work. During his long career, he never received an onscreen credit.

A pair of Foley artists creating background effects for a radio production in 1945

1933
King Kong uses stop-motion photography, a 46cm model and the travelling matte technique to combine live action with the animated footage.

1935
Fox Film Corporation, formed in 1915 by William Fox, merges with Twentieth Century Pictures to form 20th Century Fox.

1937
The first cel animated film, *Snow White and the Seven Dwarfs*, is released. Walt Disney receives an Academy Honorary Award that features a large Oscar with seven smaller ones next to it.

1939
Gone With the Wind smashes box office records. It is the first colour movie to win an Oscar for Best Picture.

1947
The fear of communism leads to Congress investigating Hollywood. 352 screenwriters, actors and directors are blacklisted.

1948
The US Supreme Court rules that major motion picture companies cannot distribute movies and own theatres without court approval.

1950
The US Government brings an end to Technicolor's monopoly on the three-strip colour film process.

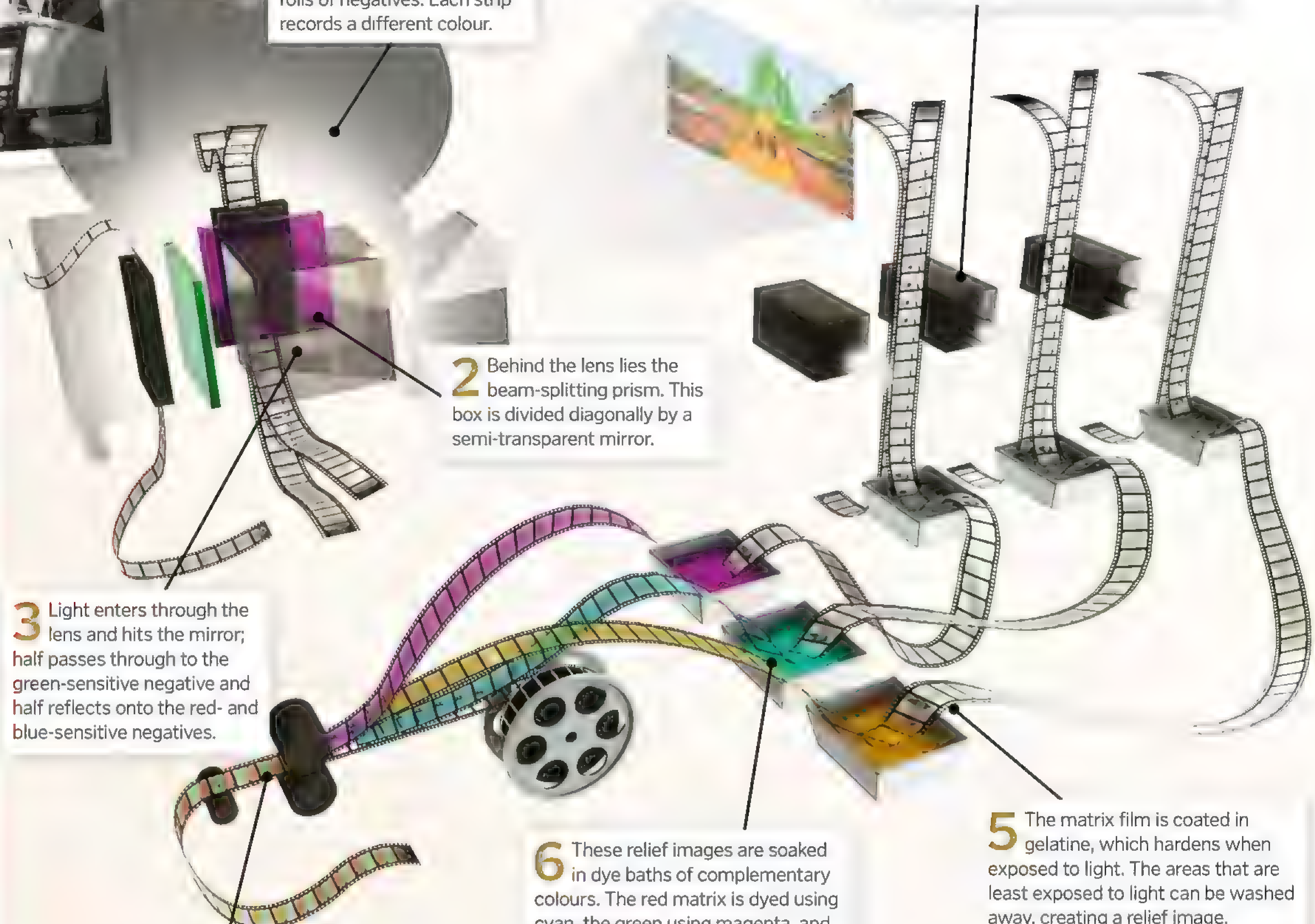
1953
How to Marry a Millionaire, starring Marilyn Monroe, is filmed in CinemaScope – a revolutionary widescreen process with stereophonic sound.

1961
The iconic red carpet is introduced at the Academy Awards.

Behind the scenes of *The Thin Man* (1934)

The tech behind Technicolor

The three-strip camera that revolutionised motion pictures between 1932 and 1954



1 The magazine (the part that resembles Mickey Mouse's ears) contains three rolls of negatives. Each strip records a different colour.

2 Behind the lens lies the beam-splitting prism. This box is divided diagonally by a semi-transparent mirror.

3 Light enters through the lens and hits the mirror; half passes through to the green-sensitive negative and half reflects onto the red- and blue-sensitive negatives.

4 The separate negatives are printed onto three strips of specially prepared film, known as 'matrix', by projecting a light through the celluloid.

5 The matrix film is coated in gelatine, which hardens when exposed to light. The areas that are least exposed to light can be washed away, creating a relief image.

6 These relief images are soaked in dye baths of complementary colours. The red matrix is dyed using cyan, the green using magenta, and the blue using yellow.

7 Each matrix is pressed against a blank film strip for several minutes. After all three transfers are complete the film is ready. The matrices can be used again and again.

Studio secrets

Unravelling some movie mysteries

Stop-motion photography

French magician and filmmaker Georges Méliès turned a pumpkin into a carriage (*Cinderella*, 1899) simply by stopping the camera, changing the object he was filming, and recording again.

Travelling mattes

Cinematographers combined scenes that were shot at different times by concealing part of the film using a 'matte'. In *The Great Train Robbery* (1903), footage of a moving locomotive was combined with footage of a robbery.

Soft focus

The glamorous glow of silver screen starlets was actually achieved using Vaseline. Applying a little petroleum jelly to the camera lens created a soft-focus, dreamy effect.

Blue-screen

The first ever Technicolor blue-screen featured in *The Thief of Bagdad* (1940). By combining the blue and green negatives to create a solid matte, the film could be combined with new footage shot against a blue screen.

The dye transfer process